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Y3. N88: 25/4116

NUREG/CR-4116

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NUFREQ-NP: A Digital Computer Code for the Linear Stability Analysis of Boiling Water Nuclear Reactors

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Prepared for
U.S. Nuclear Regulatory
Commission

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Manuscript Completed: September 1984
Date Published: July 1985

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NRC FIN B7230

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ABSTRACT

The phenonema of nuclear-coupled density-wave oscillations are of considerable importance in boiling water nuclear reactor (BWR) stability analysis. A state-of-the-art linear frequency domain digital computer code, NUFREQ-NP, has been developed for either forced or natural circulation BWR stability analysis. The NUFREQ-NP code can be excited by many external perturbations, including system pressure perturbation. It is based on one dimensional drift-flux thermal hydraulics, and allows for subcooled boiling, arbitrary nonuniform axial and radial power shapes, distributed local losses (e.g., spacers), point or multi-dimensional neutron kinetics, and detailed fuel element dynamics. It has been compared with both out-of-core and in-core data, and good agreement has been found.

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CHAPTER 1

INTRODUCTION

The stability analysis of boiling water nuclear reactors (BWRs) involves the modeling of many complex thermal-hydraulic mechanisms. Most analyses done to date have used highly simplified models and assumptions. In many cases, these have led to overly restrictive criteria for BWR design and operation. The need for accurate stability analysis has become more important with the erosion of stability margins which has accompanied newer generation plants and fuel.

An attempt to develop a detailed, mechanistic model for the analysis of nuclear-coupled density-wave oscillations in BWRs was made at Rensselaer Polytechnic Institute (RPI). This resulted in the development of a large digital computer code, called NUFREQ-N.(1) The NUFREQ-N code treats, in detail, such phenomena as the thermal-hydraulics of the BWR recirculation loop, heat transfer in the reactor fuel, and the reactor neutronics. It allows for the investigation of BWR stability from several different points-of-view, depending on the input/output variables chosen. Typical input perturbations which can be used in evaluating the system transfer functions are: coolant flow rate at the core inlet, external reactivity changes (e.g., with control rods), and the power generation rate.

Unfortunately, one of the fundamental limitations of NUFREQ-N was that its models were developed under the assumption of a constant system pressure. Consequently, this code cannot be directly used to evaluate the transfer function of a BWR system excited by external pressure perturbations. Since such techniques are, as demonstrated by the stability tests performed on the Peach Bottom reactor(2), particularly useful as experimental methods for investigating the stability of BWRs, it was deemed necessary that system pressure be used as an independent forcing variable in evaluating the transfer functions of BWR systems.

The NUFREQ-NP code constitutes an extension of NUFREQ-N, obtained by introducing the average system pressure as an independent variable in the equations modeling coolant thermal-hydraulics in the various components of the BWR recirculation loop. This new code has all the options existing in NUFREQ-N, and, in addition, evaluates the pressure-to-neutron flux (i.e., power) transfer function. Also, several improvements and modifications have been made in the models and numerics of NUFREQ-N, so that the efficiency and accuracy of NUFREQ-NP, even when it is used for the constant pressure case, are considerably better than that of NUFREQ-N.

Moreover, the NUFREQ-NP code has been assessed against representative out-of-core and in-core data, and good agreement was found.

CHAPTER 2

MODEL DESCRIPTION OF NUFREQ-NP

2.1 Overview of the NUFREQ Codes

The NUFREQ codes (NUFREQ-N and NUFREQ-NP) were developed for the linear analysis of nuclear-coupled density-wave oscillations in boiling water nuclear reactors (BWRs). The BWR loop model used is shown schematically in Figure 1.

In the hydraulic description of the core, several parallel coolant channels are defined, each associated with one or more fuel assemblies. Each channel is divided into three regions: the single-phase region, the subcooled boiling region, and the bulk boiling region. In the subcooled boiling region a mechanistic thermal non-equilibrium model(3) is used. In contrast, in the bulk boiling region, the thermal equilibrium model applies. A one-dimensional drift-flux model is used for the two-phase flow.

In order to accunt for an arbitrary nonuniform axial power distribution in the reactor core, each channel is divided into a number of axial nodes. The nodal power profile is assumed to be uniform. The model for coolant thermal-hydraulics is coupled with the one for heat transfer in the heated wall. The latter utilizes a one-dimensional transient heat conduction equation in the radial direction.

The coolant recirculation loop of a BWR is divided into several components such as upper plenum, riser/separator, and downcomer (upper and lower regions). A one-dimensional single or two-phase flow model is used for these components. Two control volumes, in particular, the lower plenum and downcomer mixing region, are treated as perfect mixing nodes. The models for coolant flow and wall heat transfer are coupled with those for reactor neutronics. The NUFREQ codes accommodate various neutronics models, such as, point kinetics, 1-D, 2-D, and 3-D nodal kinetics.

The overall BWR model, given in terms of nonlinear partial differential equations, is linearized by using first order perturbation techniques. The resultant linear equations are Laplace transformed to convert the analysis of system dynamics from the time to the frequency domain.

In their final form, the NUFREQ codes constitute a multi-input/multi-output (MIMO) linear system. In NUFREQ-N, there are three kinds of input perturbations available: coolant flow rate at the core inlet, external reactivity, and power generation rate. It was found that NUFREQ-N code generally agreed well with the existing data.(1)

Due to the assumption made in NUFREQ-N that the average pressure was time independent, this code could not be used to evaluate the transfer function in the case when system pressure perturbation was used as a forcing function. In order to overcome this limitation, a modified computer code was developed, called NUFREQ-NP. In addition to the ability to accommodate system pressure

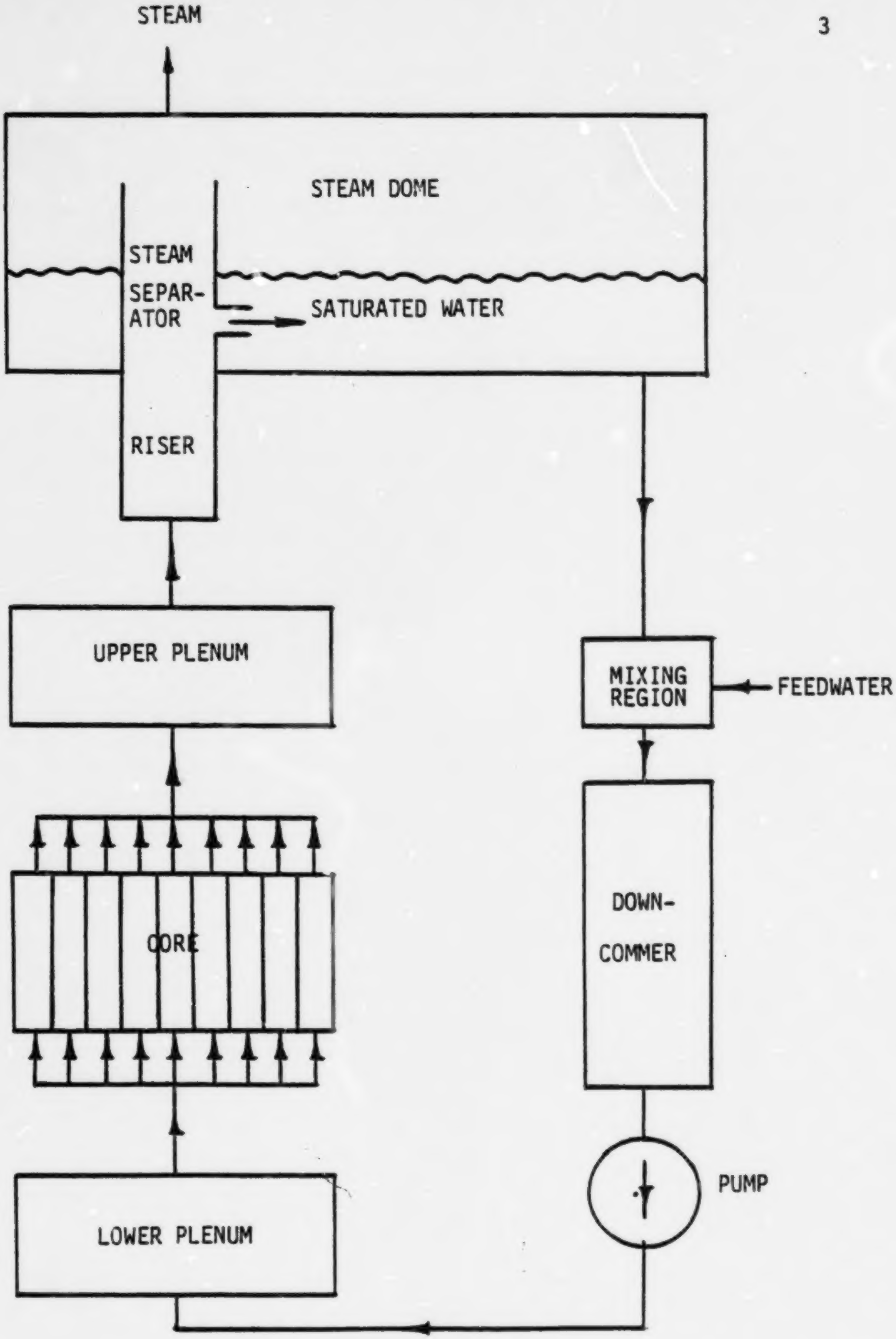
STEAM
STEAM DOME
STEAM
SEPARATOR
SATURATED WATER
RISER
UPPER PLENUM
MIXING REGION
FEEDWATER
CORE
DOWN-COMMER
PUMP
LOWER PLENUM

Figure 1 BWR Loop Model in NUFREQ-NP

perturbations, some other improvements and modifications were also made in NUFREQ-NP. The most significant of these changes were:

(1) The iteration scheme for the steady-state subcooled boiling calculation was improved.

(2) The integration scheme for transient liquid enthalpy equation was improved.

Consequently, the present version of the NUFREQ-NP code, even when used for the case of a constant system pressure, yields better and less costly results than the NUFREQ-N code.

The NUFREQ-NP code is different from NUFREQ-N only in the time dependence of system pressure. Hence, the description of the model (i.e., the assumptions, equations and notation), is almost exactly the same as those of NUFREQ-N.(1) Nevertheless, in order to make the description of NUFREQ-NP complete, all the fundamental equations will be summarized in this report, even though they are the same as those used previously. However, the new models and methods of solution, specific to NUFREQ-NP, will be discussed in detail. A complete description of the NUFREQ-N models, and the core neutronics, can be found in references 1 and 4, respectively.

As shown schematically in Fig. 1, the closed loop of a BWR is divided into six components: (1) the boiling channels, (2) the upper plenum, (3) the risers and separators, (4) the downcomer, (5) the pump, and (6) the lower plenum. For convenience, some of these components are divided into several control volumes. The details for each component will be discussed in the following sections.

2.2 Boiling Channel

The most complex component in the loop, the boiling channel, is divided into three regions: (1) the single-phase liquid region, (2) the subcooled boiling region, and, (3) the bulk boiling region.

Since the coolant is subcooled at the channel entrance, the section between the channel inlet and the void departure point is treated as a non-boiling, single-phase region. At the void departure point, the conditions are such that significant void fraction begins to appear in the subcooled water. The boiling section of the channel, which extends from the void departure point to the end of the boiling channel, is divided into two regions: the subcooled-boiling region and bulk boiling region.

The main dependent variables describing the process are the space and time dependent, volumetric flux, void fraction, pressure, and enthalpy. These are evaluated from the three fundamental laws for conservation of mass, energy and momentum and their associated constitute relations. In the course of the formulation of the channel's transfer functions, the following assumptions were made for simplicity.

(1) Since the pressure drops around the loop are small compared to the static pressure in a BWR system, an assumption is made that the properties of both the vapor and liquid depend only on the average system pressure, rather than on the local pressure. This greatly simplifies the mathematical derivation of the model, since it becomes possible to solve the continuity and energy equations, independent of the momentum equation. Indeed, rather than having a coupled problem, the results from the solution of the continuity and energy equations can be used in the momentum equation to compute the various pressure drops around the loop.

(2) In order to allow for an arbitrary axial power distribution, the model presented here is based on a node-wise constant approximation of the actual distribution.

(3) The phasic slip in the two-phase flow is given implicitly by the Zuber-Findlay drift-flux model.(3)

It should be noted that these assumptions are the same as those used in NUFREQ-N.

Finally, it was assumed in NUFREQ-NP,

(4) Perturbations in system pressure are felt uniformly throughout the loop. This implies that the relaxation time of some disturbances is much shorter than that for kinematic (i.e., density wave) disturbances. Because the characteristic frequency of density-wave oscillations is about 1 Hz, this is considered to be a good assumption.

2.2.1 Single-Phase Liquid Region

The liquid is considered to be incompressible. For a constant area channel, the equations governing single-phase flow are,

Continuity

$$\frac{\partial j_\ell}{\partial z} = 0 \qquad (2.1)$$

Thermal energy

$$\rho_\ell \left(\frac{\partial h_\ell}{\partial t} + j_\ell \frac{\partial h_\ell}{\partial z}\right) = \frac{q'' P_H}{A_{xs}} + \frac{1}{J} \frac{\partial p_\ell}{\partial t} \qquad (2.2)$$

Momentum

$$-\frac{\partial p_\ell}{\partial z} = \frac{\rho_\ell}{g_c}\left(\frac{\partial j_\ell}{\partial t} + j_\ell\frac{\partial j_\ell}{\partial z}\right) + \frac{f}{2g_c D_H}\rho_\ell j_\ell^2 + \rho_\ell\frac{g}{g_c} + \sum_{m=1}^{M_s} K_m \frac{\rho_\ell j_\ell^2}{2g_c}\delta(z-z_m) \quad (2.3)$$

where,

m is the subscript to denote local losses (i.e., due to inlet orificing, or spacers),

z_m and K_m are the position, and loss coefficient for the mth local loss, respectively.

The boundary conditions are,

$$j_\ell\Big|_{z=0} = j_{in}(t) \quad (2.4)$$

$$h_\ell\Big|_{z=0} = h_{in}(t) \quad (2.5)$$

The steady-state solutions for Eqs. (2.1) and (2.2) are, respectively,

$$j_\ell(z) = j_{in,o} \quad (2.6)$$

$$h_{\ell,k,o}(z) = h^{in}_{\ell,k,o} + \frac{P_H q''_{k,o}}{A_{xs}\rho_\ell j_{in,o}}(z - z_k) \quad (2.7)$$

for the z within the kth node (i.e., $z_k < z < z_{k+1}$).

For the purpose of linear analysis of the flow transients, Eqs. (2.1) and (2.4) were perturbed and Laplace-transformed to yield,

$$\frac{\partial \delta\hat{j}_\ell}{\partial z} = 0 \quad (2.8)$$

$$\partial\hat{j}_\ell\Big|_{z=0} = \delta\hat{j}_{in} \quad (2.9)$$

Integrating Eq. (2.8) with the boundary condition, Eq. (2.9), yields,

$$\delta\hat{j}_\ell = \delta\hat{j}_{in} \quad (2.10)$$

Similarly, perturbing and Laplace transforming Eq. (2.2) yields,

$$\frac{\partial \delta \hat{h}_{\ell,k}}{\partial z} + \frac{s}{j_{in,o}} \delta \hat{h}_{\ell,k} = \frac{P_H q''_{k,o}}{\rho_\ell A_{xs} j_{in,o}} \left(\frac{\delta \hat{q}''_k}{q''_{k,o}}\right) - \frac{q''_{k,o} P_H}{\rho_f A_{xs} j_{in,o}} \left(\frac{\delta \hat{j}_{in}}{j_{in,o}}\right) + \frac{s}{\rho_\ell j_{in,o}} \delta \hat{p} \qquad (2.11)$$

Substituting Eq. (A-6) for $\frac{\delta \hat{q}''_k}{q''_{k,o}}$ into Eq. (2.11), we obtain,

$$\frac{\partial \delta \hat{h}_{\ell,k}}{\partial z} + \phi(s)\, \delta \hat{h}_{\ell,k} = \theta(s)\, q'''_{k,o} \frac{\delta \hat{j}_{in}}{j_{in,o}} + \beta(s)\, \delta \hat{q}'''_k + \psi(s)\, \delta \hat{p} \qquad (2.12)$$

where,

$$\phi(s) = \frac{s}{j_{in,o}} + \frac{P_H}{c_{pf} \rho_\ell A_{xs} j_{in,o}} \cdot \frac{H_{1\phi,o}}{1 - H_{1\phi,o} Z_1} \qquad (2.13)$$

$$\theta(s) = \frac{P_H V_h}{\rho_\ell A_{xs} j_{in,o} A_h} \left(\frac{a}{1 - H_{1\phi,o} Z_1} - 1\right) \qquad (2.14)$$

$$\beta(s) = \frac{P_H}{\rho_\ell A_{xs} j_{in,o}} \cdot \frac{H_{1\phi,o} Z_2}{1 - H_{1\phi,o} Z_1} \qquad (2.15)$$

$$\psi(s) = \frac{s}{\rho_\ell J j_{in,o}} + \left(\frac{P_H}{c_{pf} \rho_\ell A_{xs} j_{in,o}}\right) \left(\frac{H_{1\phi,o}}{1 - H_{1\phi,o} Z_1}\right) \left(\frac{1 - \beta_p T_\infty}{\rho_f}\right) \qquad (2.16)$$

The appropriate boundary condition for Eq. (2.12) is obtained from Eq. (2.5) as,

$$\delta \hat{h}_\ell \Big|_{z=0} = \delta \hat{h}_{in} \qquad (2.17)$$

Performing the integration of Eq. (2.12) from the channel entrance (z=0) to the void departure point ($z = z_{do}$), yields,

$$\delta \hat{h}_{\ell,k}(s, z_{d,o}) = H_1(s)\, \delta \hat{j}_{in} + H_2(s) \sum_{k=1}^{L} H'_k\, \delta \hat{q}'''_k + H_3(s)\, \delta \hat{h}_{in} + H_4(s)\, \delta \hat{p} \qquad (2.18)$$

where,

$$H_1(s) = \frac{\theta(s)}{\phi(s)} \cdot \frac{e^{-\phi(s)z_{d,o}}}{j_{in,o}} \sum_{k=1}^{L_1} \left(e^{\phi(s)z_k} - e^{\phi(s)z_{k-1}}\right) q'''_{k,o} \tag{2.19}$$

$$H_2(s) = \frac{\beta(s)}{\phi(s)} e^{-\phi(s)z_{d,o}} \tag{2.20}$$

$$H_3(s) = e^{-\phi(s)z_{d,o}} \tag{2.21}$$

$$H_4(s) = \frac{\psi(s)}{\phi(s)} \left(1 - e^{-\phi(s)z_{d,o}}\right) \tag{2.22}$$

$$H'_k = e^{\phi(s)z_k} - e^{\phi(s)z_{k-1}} \tag{2.23}$$

The transfer functions, $H_i(s)$ $(i=1,2,3)$ are exactly the same as those in NUFREQ-N,(1) while, $H_4(s)$ accounts for the effect of system pressure perturbation on the enthalpy response at the void departure point.

The steady-state form of the momentum equation, Eq. (2.3) is,

$$-\frac{dp_o}{dz} = \frac{\rho_{\ell o} j_{\ell o}}{g_c} \frac{dj_{\ell o}}{dz} + \frac{f}{2g_c D_H} \rho_{\ell o} j_{\ell o}^2 + \rho_{\ell o} \frac{g}{g_c} + \sum_{m=1}^{M_s} K_m \frac{\rho_{\ell o} j_{\ell o}^2}{2g_c} \delta(z - z_m) \tag{2.24}$$

Integrating Eq. (2.24) from $z=0$ to $z=z_{d,o}$, yields,

$$\Delta p_{o,1\phi} \overset{\Delta}{=} \int_0^{z_{d,o}} \left(-\frac{dp_o}{dz}\right) dz = \frac{\rho_{\ell o}}{2g_c} \int_0^{z_{d,o}} \frac{dj_{\ell o}^2}{dz} dz + \frac{f\rho_{\ell o}}{2g_c D_H} \int_0^{z_{d,o}} j_{\ell o}^2 dz + \frac{\rho_{\ell o} g}{g_c} z_{d,o}$$

$$+ \sum_{m=1}^{M_s} k_m \frac{\rho_{\ell o} j_{\ell o}^2(z_m)}{2g_c} \tag{2.25}$$

Using Eq. (2.6), we obtain,

$$\Delta p_{o,1\phi} = \frac{f\rho_{\ell o} j_{in,o}^2}{2g_c D_H} z_{d,o} + \frac{\rho_{\ell o} g z_{d,o}}{g_c} + \sum_{m=1}^{M_s} K_m \frac{\rho_{\ell o} j_{in,o}^2}{2g_c} \tag{2.26}$$

The transient single-phase pressure drop can be obtained by integrating Eq. (2.3) from the inlet of the channel (z=0) to the void departure point ($z=z_d(t)$), that is,

$$\Delta p_{1\phi}(t) = \int_0^{z_d(t)} \left(-\frac{\partial p}{\partial z}\right) dz \tag{2.27}$$

Linearizing and taking Laplace transforming Eq. (2.27), yields,

$$\delta(\Delta\hat{p}_{1\phi}) = \int_0^{z_{d,o}} \left(-\frac{\partial\delta\hat{p}}{\partial z}\right) dz - \frac{dp_o(z_{d,o})}{dz}\,\delta\hat{z}_d \tag{2.28}$$

By linearizing and Laplace transforming Eq. (2.3), we obtain,

$$-\frac{\partial\delta\hat{p}}{\partial z} = \frac{\rho_{\ell o}}{g_c}\left(s\,\delta\hat{j}_\ell + j_{\ell o}\frac{\partial\delta\hat{j}_\ell}{\partial z}\right) + \frac{f\rho_{\ell o}j_{\ell o}}{g_c D_H}\,\delta\hat{j}_\ell + \sum_{m=1}^{M_s} K_m \frac{\rho_{\ell o}j_{\ell o}}{g_c}\,\delta\hat{j}_\ell\,\delta(z - z_m) \tag{2.29}$$

Substituting Eq. (2.29) into Eq. (2.28), and performing the integration, the channel single-phase pressure drop perturbation becomes,

$$\delta(\Delta\hat{p}_{1\phi}) = \Gamma_1(s)\,\delta\hat{j}_{in} + C_2\delta\hat{Z}_d \tag{2.30}$$

where,

$$\Gamma_1(s) \overset{\Delta}{=} \left(\frac{\rho_{\ell o}s}{g_c} + \frac{f\rho_{\ell o}j_{in,o}}{g_c D_H}\right) z_{d,o} + \sum_{m=1}^{M_s} K_m \frac{\rho_{\ell o}j_{in,o}}{g_c} \tag{2.31}$$

$$C_2 \overset{\Delta}{=} -\left.\frac{dp}{dz}\right|_{z=z_{d,o}} = \frac{fG_o^2}{2g_c D_H \rho_f} + \frac{g}{g_c}\rho_f \tag{2.32}$$

Using Eq. (D.23), Eq. (2.30) can be rewritten as,

$$\delta(\Delta\hat{p}_{1\phi}) = \Gamma_1^*(s)\,\delta\hat{j}_{in} + \sum_{k=1}^{L} \Gamma_{2,k}^*(s)\,\delta\hat{q}_k''' + \Gamma_3^*(s)\,\delta\hat{h}_{in} + \Gamma_4^*(s)\,\delta\hat{p} \tag{2.33}$$

where,

$$\Gamma_1^*(s) = \Gamma_1(s) + C_2\Lambda_1(s) \tag{2.34}$$

$$\Gamma_{2,k}^*(s) = C_2\Lambda_{2,k} \tag{2.35}$$

$$\Gamma_3^*(s) = C_2\Lambda_3(s) \tag{2.36}$$

$$\Gamma_4^*(s) = C_2\Lambda_4(s) \tag{2.37}$$

As before, if the last term on the right hand side of Eq. (2.33) is ignored, this equation becomes identical to the expression used in NUFREQ-N. That is, the appearance of the transfer function $\Gamma_4^*(s)$ is the only difference between previous analyses.(1)

2.2.2 Two-Phase Region

Assuming liquid phase incompressibility, the governing equations for the kth node in the two-phase region are:

Mixture continuity equation

$$\frac{\partial\langle j\rangle_k}{\partial z} = v_{\ell g}\,\Gamma_k - \frac{\langle\alpha\rangle_k}{\rho_g}\frac{\partial\rho_g}{\partial t} \tag{2.38}$$

Void propagation equation

$$\frac{\partial\langle\alpha\rangle_k}{\partial t} + (C_K)_k\frac{\partial\langle\alpha\rangle_k}{\partial z} = \frac{\Gamma_k}{\rho_g} - \frac{\langle\alpha\rangle_k}{\rho_g}\frac{\partial\rho_g}{\partial t} - \langle\alpha\rangle_k\,C_{o,k}\frac{\partial\langle j\rangle_k}{\partial z} \tag{2.39}$$

Liquid-phase energy equation (for the subcooled boiling region)

$$\rho_\ell(1-\langle\alpha\rangle_k)\left(\frac{\partial h_{\ell,k}}{\partial t} + u_{\ell,k}\frac{\partial h_{\ell,k}}{\partial z}\right) = \frac{P_H q''_k}{A_{xs}} + \frac{1}{J}\frac{dp}{dt} - \Gamma_k(h_g-h_{\ell,k}) - \rho_g\langle\alpha\rangle_k\frac{dh_g}{dt} \tag{2.40}$$

Vapor generation rate

(a) If $h_{\ell d} < h_{\ell,k} < h_f(1-\varepsilon)$ (i.e., the kth node is in the subcooled boiling region),

$$\Gamma_k = \left(\frac{P_H q''_k}{A_{xs}}\right)\cdot\frac{\rho_g(h_{\ell,k}-h_{\ell d})}{(h_f-h_{\ell d})\,\{\rho_g h_{fg} + \rho_f(h_f-h_{\ell,k})\}} - \frac{H_o\langle\alpha\rangle_k}{v_{fg}C_{pf}}(h_f-h_{\ell,k})$$

$$+ \frac{1}{h_{fg}}\left[\frac{1}{J}\frac{dp}{dt} - \rho_f(1-\langle\alpha\rangle_k)\frac{dh_f}{dt} - \rho_g\langle\alpha\rangle_k\frac{dh_g}{dt}\right] \tag{2.41}$$

(b) If $h_f(1-\varepsilon) < h_{\ell,k}$ (i.e., the k^{th} node is in the bulk boiling region),

$$\Gamma_k = \frac{1}{h_{fg}} \left[\frac{P_H q''_k}{A_{xs}} + \frac{1}{J}\frac{dp}{dt} - \rho_f(1-\langle\alpha\rangle_k)\frac{dh_f}{dt} - \rho_g\langle\alpha\rangle_k\frac{dh_g}{dt}\right] \tag{2.42}$$

Mixture momentum equation

$$-\frac{\partial p}{\partial z} = \frac{1}{g_c}\frac{\partial G}{\partial t} + \frac{1}{g_c}\frac{\partial G'}{\partial z} + \frac{1}{g_c}\frac{\partial S_{DG}}{\partial z} + \frac{g}{g_c}\langle\bar{\rho}\rangle + \frac{fG^2}{2g_c\rho_f D_H}\phi^2_{\ell o}$$

$$+ \sum_{m=M_s+1}^{Mt} K_{spacer,m}\frac{G^2\Phi}{2g_c\rho_f}\delta(z-z_m) + K_{exit}\frac{G^2}{2g_c\rho_f}\Phi\delta(z-L_H) \tag{2.43}$$

The last two terms on the right hand side of the above equation account for local loss due to grid spacers and the exit restriction, respectively. Also,

$$G' \triangleq \frac{G^2}{\langle\bar{\rho}\rangle} \tag{2.44}$$

$$S_{DG} \triangleq \left(\frac{\rho_f-\langle\bar{\rho}\rangle}{\langle\bar{\rho}\rangle-\rho_g}\right)\left(\frac{\rho_f\rho_g}{\langle\bar{\rho}\rangle}\right)(V'_{gj})^2 \tag{2.45}$$

$$\langle\bar{\rho}\rangle \triangleq \rho_f(1-\langle\alpha\rangle) + \rho_g\langle\alpha\rangle \tag{2.46}$$

$$V'_{gj} \triangleq V_{gj} + (C_o-1)\langle j\rangle \tag{2.47}$$

The derivation of the perturbations in volumetric flux and void fraction in the subcooled and bulk boiling regions are shown in Appendices B and E, respectively. Note that by comparing Eq. (E-37) with Eq. (B-41) and Eq. (E-18) with Eq. (B-23), the $\delta\hat{\Omega}_p$ in Appendix E is equivalent to the $\delta\hat{\bar{\Omega}}_{q,k}$ in Appendix B. Hence, the results in Appendix B can be extended to the bulk boiling region by simply adjusting $\delta\hat{\bar{\Omega}}_{q,k}$ and the coefficients, (A_1, B_1, B_2, C_2, D_2, E_2) for bulk boiling region.

Let us now consider the two-phase pressure drop in the channel. The pressure drop across the two-phase region is,

$$\Delta p_{2\phi} = \int_{z_d}^{L_H} \left(-\frac{\partial p}{\partial z}\right) dz \tag{2.48}$$

Perturbing and Laplace transforming Eq. (2.48) yields,

$$\delta(\Delta\hat{p}_{2\phi}) = \int_{z_{d,o}}^{L_H} \left(-\frac{\partial\delta\hat{p}}{\partial z}\right) dz - \left(-\frac{dp}{dz}\right)\Bigg|_{z_{d,o}} \delta\hat{z}_d$$

or,

$$\delta(\Delta\hat{p}_{2\phi}) = \sum_{k=d}^{N_t} \int_{z_k}^{z_{k+1}} \left(-\frac{\partial\delta\hat{p}_k}{\partial z}\right) dz + \frac{dp}{dz}\Bigg|_{z_{d,o}} \delta\hat{z}_d \tag{2.49}$$

The term $\left(\partial(\delta\hat{p}_k)/\partial z\right)$ can be obtained from perturbating and Laplace transforming Eq. (2.43). Ignoring spacers, the perturbation in pressure drop across the kth node becomes,

$$\delta(\Delta\hat{p}'_{2\phi})_k \triangleq \frac{(C_{K,o})_k^{IN}}{C_{o,k,o}\Omega_{k,o}g_c} \int_1^{\xi_k^{OUT}} \left[s\delta\hat{G} + \frac{C_{o,k,o}\Omega_{k,o}}{(C_{K,o})_k^{IN}} \frac{\partial\delta\hat{G}'_k}{\partial\xi_k} + \frac{fG_o\phi_{\ell o}^2}{\rho_f D_H}\delta\hat{G}_k\right.$$

$$\left. + \frac{fG_o^2}{2D_H\rho_f}\delta\hat{\phi}_{\ell o}^2 + g\delta\langle\hat{\bar{\rho}}\rangle + \frac{C_{o,k,o}\Omega_{k,o}}{(C_{K,o})_k^{IN}} \frac{\partial}{\partial\xi_k}\delta\hat{S}_{DG}\right] d\xi_k,$$

$$\delta(\Delta\hat{p}'_{2\phi})_k = \frac{(C_{K,o})_k^{IN}}{C_{o,k,o}\Omega_{k,o}g_c} \left\{s\int_1^{\xi_k^{OUT}} \delta\hat{G}_k\, d\xi_k + \frac{C_{o,k,o}\Omega_{k,o}}{(C_{K,o})_k^{IN}}\left(\delta\hat{G}_k'^{OUT} - \delta\hat{G}_k'^{IN}\right)\right.$$

$$+ \frac{fG_o\bar{\phi}_{\ell o}^2}{\rho_f D_H}\int_1^{\xi_k^{OUT}} \delta\hat{G}_k d\xi_k + \frac{fG_o^2}{2D_H\rho_f}\int_1^{\xi_k^{OUT}} \delta\hat{\phi}_{\ell o}^2\, d\xi_k + g\int_1^{\xi_k^{OUT}} \delta\langle\hat{\bar{\rho}}\rangle\, d\xi_k$$

$$\left. + \frac{C_{o,k,o}\Omega_{k,o}}{(C_{K,o})_k^{IN}}\left(\delta\hat{S}_{DG}^{OUT} - \delta\hat{S}_{DG}^{IN}\right)\right\} \tag{2.50}$$

Note that the ξ_k (or ξ_k^{OUT}) is defined in Eq. (E-10).

By Eqs. (F-2), (F-8), and (F-40), the integrals in Eq. (2.50) can be evaluated as,

$$\int_1^{\xi_k^{OUT}} \delta\hat{G}_k d\xi_k = \vec{G}^*_{1,k}\ \delta\langle\hat{j}\rangle_k^{IN} + \vec{G}^*_{2,k}\ \delta\langle\hat{\alpha}\rangle_k^{IN} + \vec{G}^*_{3,k}\ \delta\hat{\bar{\Omega}}_{q,k} + \vec{G}^*_{4,k}\ \delta\hat{p} \tag{2.51}$$

$$\int_1^{\xi_k^{OUT}} \delta\hat{\phi}^2_{\ell o}\ d\xi_k = \vec{P}^*_{1,k}\ \delta\langle\hat{j}\rangle_k^{IN} + \vec{P}^*_{2,k}\ \delta\langle\hat{\alpha}\rangle_k^{IN} + \vec{P}^*_{3,k}\ \delta\hat{\bar{\Omega}}_{q,k} + \vec{P}^*_{4,k}\ \delta\hat{p} \tag{2.52}$$

$$\int_1^{\xi_k^{OUT}} \delta\langle\hat{\bar{\rho}}\rangle\ d\xi_k = \vec{R}^*_{1,k}\ \delta\langle\hat{j}\rangle_k^{IN} + \vec{R}^*_{2,k}\ \delta\langle\hat{\alpha}\rangle_k^{IN} + \vec{R}^*_{3,k}\ \delta\hat{\bar{\Omega}}_{q,k} + \vec{R}^*_{4,k}\ \delta\hat{p} \tag{2.53}$$

where,

$$\vec{G}^*_{1,k} = g_{1,k}\ln\xi_k^{OUT} - \frac{g_{2,k}}{2-A_2}\left[1 - (\xi_k^{OUT})^{2-A_2}\right] \tag{2.54}$$

$$\vec{G}^*_{2,k} = -\frac{g_{6,k}}{2-A_2}\left[1 - (\xi_k^{OUT})^{2-A_2}\right] \tag{2.55}$$

$$\vec{G}^*_{3,k} = g_{3,k}(\xi_k^{OUT} - 1) + g_{4,k}\ln\xi_k^{OUT} + \frac{g_{5,k}}{2-A_2}\left[(\xi_k^{OUT})^{2-A_2} - 1\right] \tag{2.56}$$

$$\vec{G}^*_{4,k} = (\xi_k^{OUT} - 1)\ g_{7,k} + \ln\xi_k^{OUT}\cdot g_{9,k} + \frac{1}{2}\left[(\xi_k^{OUT})^2 - 1\right] g_{8,k} + \frac{1}{2-A_2}\cdot$$

$$\left[(\xi_k^{OUT})^{2-A_2} - 1\right] g_{10,k} + \frac{1}{2}(\ln\xi_k^{OUT})^2\ g_{11,k} \tag{2.57}$$

$$\overrightarrow{P}^{*}_{1,k} = f_{1,k}(\xi_k^{OUT} - 1) + f_{2,k}\ln\xi_k^{OUT} + \frac{f_{3,k}}{2 - A_2}[(\xi_k^{OUT})^{2-A_2} - 1]$$

$$+ \frac{f_{4,k}}{3 - A_2}[(\xi_K^{OUT})^{3-A_2} - 1] \qquad (2.58)$$

$$\overrightarrow{P}^{*}_{2,k} = \frac{f_{10,k}}{2 - A_2}[(\xi_k^{OUT})^{2-A_2} - 1] + \frac{f_{11,k}}{3 - A_2}[(\xi_k^{OUT})^{3-A_2} - 1] \qquad (2.59)$$

$$\overrightarrow{P}^{*}_{3,k} = f_{5,k}(\xi_k^{OUT} - 1) + f_{6,k}\ln\xi_k^{OUT} + \frac{f_{7,k}}{2}[(\xi_k^{OUT})^2 - 1]$$

$$+ \frac{f_{8,k}}{2 - A_2}[(\xi^{OUT})^{2-A_2} - 1] + \frac{f_{9,k}}{3 - A_2}[(\xi^{OUT})^{3-A_2} - 1] \qquad (2.60)$$

$$\overrightarrow{P}^{*}_{4,k} = f_{12,k}(\xi_k^{OUT} - 1) + f_{13,k}\ln\xi_k^{OUT} + \frac{f_{14,k}}{2}[(\xi_k^{OUT})^2 - 1]$$

$$+ \frac{f_{15,k}}{3}[(\xi_k^{OUT})^3 - 1] + \frac{f_{16,k}}{2 - A_2}[(\xi_k^{OUT})^{2-A_2} - 1]$$

$$+ \frac{f_{17,k}}{3 - A_2}[(\xi_k^{OUT})^{3-A_2} - 1] + f_{18,k}[\xi_k^{OUT}(\ln\xi_k^{OUT} - 1) + 1]$$

$$+ \frac{f_{19,k}}{2}(\ln\xi_k^{OUT})^2 \qquad (2.61)$$

$$\overrightarrow{R}^{*}_{1,k} = -\Delta\rho\ C_{o,k,o}\bar{\Omega}_{ko}\ P_{2,k}\ \{(\xi_k^{OUT})^{-1} - 1 + \frac{1}{1-A_2}[(\xi_k^{OUT})^{1-A_2} - 1]\} \qquad (2.62)$$

$$\overline{R}^{*}_{2,k} = -\frac{\Delta\rho}{1-A_2}\left[(\xi_k^{OUT})^{1-A_2} - 1\right] \tag{2.63}$$

$$\overline{R}^{*}_{3,k} = \Delta\rho\,(C_{K,o})_k^{IN}\,P_{2,k}\left\{(\xi_k^{OUT})^{-1} - 1 + \frac{1}{1-A_2}\left[(\xi_k^{OUT})^{1-A_2} - 1\right]\right\} \tag{2.64}$$

$$\begin{aligned}\overline{R}^{*}_{4,k} = \Delta\rho\,\{\, & P_{3,k}\left[\xi_k^{OUT} - 1 - \frac{1}{1-A_2}\left(\xi_k^{OUT\ 1-A_2} - 1\right)\right] \\ & + P_{4,k}\left[\ell n\xi_k^{OUT} - \frac{1}{1-A_2}\left(\xi_k^{OUT^{1-A_2}} - 1\right)\right] + P_{5,k}\left[\left(1 - \xi_k^{OUT^{-1}}\right)\right. \\ & \left. - \frac{1}{1-A_2}\left(\xi_k^{OUT^{1-A_2}} - 1\right)\right] + P_{6,k}\left[-\xi_k^{OUT^{-1}}\left(1 + \ell n\xi_k^{OUT}\right) + 1\right. \\ & + \frac{1}{(1-A_2)(A_2-2)}\left(\xi_k^{OUT\ 1-A_2} - 1\right) - \frac{\rho_f}{C_{oko}\Delta\rho}\left(\xi_k^{OUT} - 1\right)\frac{d\Delta\rho}{dp} \\ & \left. + \frac{1}{C_{o,k,o}\Delta\rho}\frac{d\Delta\rho}{dp}\left(\rho_f - C_{o,k,o}\Delta\rho\langle\alpha_o\rangle_k^{IN}\right)\ell n\xi_k^{OUT} + \frac{1}{A_2-2}\left(\xi_k^{OUT^{-1}} - 1\right)\right]\}\end{aligned} \tag{2.65}$$

$$\begin{aligned}g_{7,k} = {} & A_{1s}\left(\rho_f - \Delta\rho C_{o,k,o}\langle\alpha_o\rangle_k^{IN}\right) - \Delta\rho(C_{K,o})_k^{IN}\,P_{4,k} + \frac{1}{C^2_{o,k,o}\Delta\rho}\left[\rho_f V_{gj}\right. \\ & \left. + (C_{K,o})_k^{IN}\left(\rho_f - \Delta\rho C_{o,k,o}\langle\alpha_o\rangle_k^{IN}\right)\right]\left(C_{o,k,o}\frac{d\Delta\rho}{dp} + \Delta\rho\frac{dC_{o,k,o}}{dp}\right) \\ & - \frac{\rho_f}{C_{o,k,o}\Delta\rho}\left(V_{gj}\frac{d\Delta\rho}{dp} + \Delta\rho\frac{dV_{gj}}{dp}\right)\end{aligned} \tag{2.66}$$

$$g_{8,k} = -\Delta\rho(C_{K,o})_k^{IN}\,P_{3,k} - \frac{\rho_f}{C^2_{o,k,o}\Delta\rho}\left(C_{o,k,o}\frac{d\Delta\rho}{dp} + \Delta\rho\frac{dC_{o,k,o}}{dp}\right)(C_{K,o})_k^{IN} \tag{2.67}$$

$$\begin{aligned}g_{9,k} = {} & \left(\rho_f - C_{o,k,o}\Delta\rho\langle\alpha_o\rangle_k^{IN}\right)\left(\frac{1}{C_{o,k,o}}\frac{dV_{gj}}{dp} - \frac{V_{gj}}{C^2_{o,k,o}}\frac{dC_{o,k,o}}{dp} - A_{1s}\right) \\ & - \Delta\rho(C_{K,o})_k^{IN}\left(P_{5,k} + \frac{P_{6,k}}{2-A_2}\right)\end{aligned} \tag{2.68}$$

$$g_{10,k} = \Delta\rho (C_{K,o})_k^{IN} \left(P_{3,k} + P_{4,k} + P_{5,k} - \frac{P_{6,k}}{A_2-2}\right) \tag{2.69}$$

$$g_{11,k} = \left(\rho_f - \Delta\rho\, C_{o,k,o}\langle\alpha_o\rangle_k^{IN}\right) B_{1s} - \Delta\rho (C_{K,o})_k^{IN} P_{6,k} \tag{2.70}$$

Substituting Eqs. (2.51)-(2.53), (F-15) and (F-20) into Eq. (2.50) yields,

$$\delta(\Delta\hat{p}'_{2\phi})_k = D_{1,k}\,\delta\langle\hat{j}\rangle_k^{IN} + D_{2,k}\,\delta\langle\hat{\alpha}\rangle_k^{IN} + D_{3,k}\delta\hat{\bar{\Omega}}_{q,k} + D_{4,k}\delta\hat{p} \tag{2.71}$$

where,

$$D_{i,k} \triangleq \frac{(C_{K,o})_k^{IN}}{C_{o,k,o}\bar{\Omega}_{k,o}g_c}\Big\{\Big(s + \frac{fG_o\phi^2_{\ell o}}{\rho_f D_H}\Big)\bar{G}^*_{i,k} + \frac{fG_o^2}{2D_H\rho_f}\bar{P}^*_{i,k} + g\,\bar{R}^*_{i,k}$$

$$+ \frac{C_{o,k,o}\bar{\Omega}_{k,o}}{(C_{K,o})_k^{IN}}\left(G'^{OUT}_{i,k} + S^{OUT}_{i,k} - G'^{IN}_{i,k} - S^{IN}_{i,k}\right)\Big\} \tag{2.72}$$

Next, the local pressure drop perturbation due to spacers, or at the channel exit can be evaluated as,

$$\delta(\Delta\hat{p}_{2\phi})_\ell\,(z_m) \triangleq K_{s,m}\left\{\frac{G_o\Phi}{g_c\rho_f}\bigg|_{z=z_m}\delta\hat{G}(s,z_m) + \frac{G_o^2}{2g_c\rho_f}\bigg|_{z=z_m}\delta\hat{\Phi}(s,z_m)\right\}$$

$$= C_{1,m}\,\delta\langle\hat{j}\rangle_k^{IN} + C_{2,m}\,\delta\langle\hat{\alpha}\rangle_k^{IN} + C_{3,m}\,\delta\hat{\bar{\Omega}}_{q,k} + C_{4,m}\,\delta\hat{p} \tag{2.73}$$

where,

$$C_{i,m} \triangleq K_{s,m}\left\{\frac{G_o\Phi}{g_c\rho_f}\bigg|_{z=z_m} G_{i,m} + \frac{G_o^2}{2g_c\rho_f}\bigg|_{z=z_m} P_{i,m}\right\} \tag{2.74}$$

and with $G_{i,m}$ and $P_{i,m}$ $(i=1,2,3,4)$ given by Eqs. (F-9) and (F-32), respectively. Hence, the total pressure drop perturbation in the k^{th} node (two-phase region) can be written as,

$$\delta(\Delta\hat{p}_{2\phi})_k \triangleq \int_{z_k}^{z_{k+1}} \left(-\frac{\partial\delta\hat{p}}{\partial z}\right) dz = \delta(\Delta\hat{p}'_{2\phi})_k + \sum_{m\in M_k} \delta(\Delta\hat{p}_{2\phi})_\ell\,(z_m)$$

$$= D^*_{1,k}\;\delta\langle\hat{j}\rangle_k^{in} + D^*_{2,k}\;\delta\langle\hat{\alpha}\rangle_k^{in} + D^*_{3,k}\;\delta\hat{\bar{\Omega}}_{q,k} + D^*_{4,k}\;\delta\hat{p} \tag{2.75}$$

Where M_k extends over all the spacers in the k^{th} node, and,

$$D^*_{i,k} = D_{i,k} + \sum_{m\in M_k} C_{i,m} \qquad \text{for } i = 1,\ 2,\ 3,\ 4 \tag{2.76}$$

Substituting Eqs. (2.75) into (2.49) yields,

$$\delta(\Delta\hat{p}_{2\phi}) = \sum_{k=d}^{N_t} \{D^*_{1,k}\;\delta\langle\hat{j}\rangle_k^{IN} + D^*_{2,k}\;\delta\langle\hat{\alpha}\rangle_k^{IN} + D^*_{3,k}\;\delta\hat{\bar{\Omega}}_{q,k} + D^*_{4,k}\;\delta\hat{p}\} + \left.\frac{dp}{dz}\right|_{z_{d,o}} \delta\hat{z}_d \tag{2.77}$$

By using Eqs. (B-145), (B-151)-(B-152) for $\delta\hat{\bar{\Omega}}_{q,k}$, $\delta\langle\hat{j}\rangle_k^{IN}$ and $\delta\langle\hat{\alpha}\rangle_k^{IN}$, Eq. (2.77) becomes,

$$\delta(\Delta\hat{p}_{2\phi}) = \pi_1\;\delta\hat{j}_{in} + \pi_2^{1\phi}\sum_{\ell=1}^{L} H'_\ell\;\delta\hat{q}_\ell''' + \sum_{k=d}^{N_t}\pi_2^k\;\delta\hat{q}_k''' + \pi_3\;\delta\hat{h}_{in} + \pi_4\;\delta\hat{p}$$

$$+ \left.\frac{dp}{dz}\right|_{z_{d,o}} \delta\hat{z}_d \tag{2.78}$$

where,

$$\pi_1 = \sum_{k=d}^{N_t} \{D^*_{1,k}\;B_{1,k} + D^*_{2,k}\;K_{1,k} + D^*_{3,k}\;M_{1,k}\} \tag{2.79}$$

$$\pi_1^{1\phi} = \sum_{k=d}^{N_t} \{D^*_{1,k}\;B^{1\phi}_{2,k} + D^*_{2,k}\;K^{1\phi}_{2,k} + D^*_{3,k}\;M^{1\phi}_{2,k}\} \tag{2.80}$$

$$\pi_2^k = \begin{cases} \sum_{i=k+1}^{N_t} \{D_{1,i}^* \; B_{2,i}^k + D_{2,i}^* \; K_{2,i}^k + D_{3,i}^* \; M_{2,i}^k\} + D_{3,k}^* \; M_{2,k}^k \;, \text{ if } k < N_t \\ \\ D_{3,k}^* \; M_{2,k}^k \;, \text{ if } k = N_t \end{cases} \tag{2.81}$$

$$\pi_3 = \sum_{k=d}^{N_t} \{D_{1,k}^* \; B_{3,k} + D_{2,k}^* \; K_{3,k} + D_{3,k}^* \; M_{3,k}\} \tag{2.82}$$

$$\pi_4 = \sum_{k=d}^{N_t} \{D_{1,k}^* \; B_{4,k} + D_{2,k}^* \; K_{4,k} + D_{3,k}^* \; M_{4,k} + D_{4,k}^*\} \tag{2.83}$$

Again, we note that the only new term associated with system pressure perturbation is the transfer function, $\pi_4(s)$.

2.3 Heated Wall Dynamics

The model for heated wall dynamics in NUFREQ-NP is the same as that used in NUFREG-N.(1) This model accounts for three different heated wall geometries: flat plate, hollow cylinder, and BWR fuel rod.

The derivation of the transfer functions for all three geometries is based on the following assumptions:

(1) The steady-state characteristics in the coolant channel are known at the desired operating conditions; hence local operating conditions on the boiling curve are predetermined.

(2) The length of the heater is much larger than its thicnkess; thus, a one-dimensional heat conduction model (in the direction perpendicular to that of the coolant flow) can be applied.

(3) Fuel, gap, and clad properties (density, heat capacity, gap conductance, etc.) are assumed to be constant.

(4) Radiation heat transfer is neglected.

As an example, for a BWR fuel rod, such is that shown in Fig. 2, the governing equations and boundary conditions are:

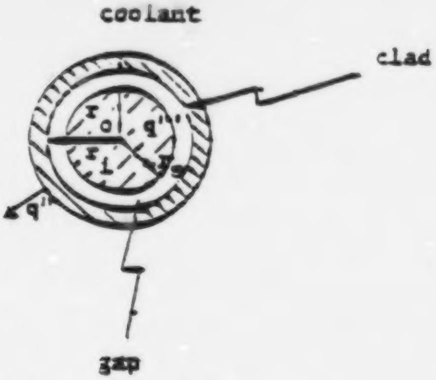

Figure 2. BWR fuel rod.

Fuel Region

$$\rho_F C_{pF} \frac{\partial T_F}{\partial t} = \frac{\kappa_F}{r} \frac{\partial}{\partial r} \left(r \frac{\partial T_F}{\partial r} \right) + q''' \tag{2.84}$$

Cladding Region

$$\rho_c C_{pc} \frac{\partial T_c}{\partial t} = \frac{\kappa_c}{r} \frac{\partial}{\partial r} \left(r \frac{\partial T_c}{\partial r} \right) \tag{2.85}$$

Boundary Conditions

$$- \kappa_F \frac{\partial T_F}{\partial r} \bigg|_{r=0} = 0 \tag{2.86}$$

$$- \kappa_F \frac{\partial T_F}{\partial r} \bigg|_{r=r_s} = \frac{r_i}{r_s} q''_i \tag{2.87}$$

$$- \kappa_c \frac{\partial T_F}{\partial r} \bigg|_{r=r_i} = q''_i = H_g[T_F(r_s,t) - T_c(r_i,t)] \tag{2.88}$$

$$- \kappa_c \frac{\partial T_F}{\partial r} \bigg|_{r=r_o} = \begin{cases} H_{1\phi}[T_c(r_o,t) - T_\infty(t)] & \text{for single-phase region} \\ K[T_c(r_o,t) - (T_{sat})]^m & \text{for two-phase region} \end{cases} \tag{2.89}$$

After linearizing and Laplace transforming Eqs. (2.84)-(2.89), we obtain,(1)

$$\delta\hat{T}_{w,k} \overset{\Delta}{=} \delta\hat{T}_{c,k}(r=r_o) = Z_1\, \delta\hat{q}''_k + Z_2\, \delta\hat{q}'''_k \tag{2.90}$$

Note that we can also obtain similar results for other geometries. The Z_1 and Z_2 for all the three geometries can be found in Ref. 1. Equation (2.90) is used in deriving the heat flux perturbations; details are shown in Appendix-A.

2.4 Multichannel Analysis

The procedure used in NUFREQ-NP and NUFREQ-N is to use a given recirculation flow and a guessed pressure drop across all channels. This provides both the pressure drop and total flow requirements for the parallel channels in the core. Firstly, this pressure drop is used in an iterative scheme to calculate the flow rate in each core channel type. Next, the flow rates in all the channels are summed up and compared to the given flow. If the difference between the two flow rates exceeds the tolerance specified, the pressure drop is adjusted and the process repeated until the convergence criteria for both the flow rates and pressure are satisfied. More details about the iteration process can be found in Ref. 1. In other words, in the multichannel analysis, some inherent assumptions are made as follows:

(1) The loop condition gives,

$$\Delta p_i + \Delta p_{ext,loop} = 0 \tag{2.91}$$

for channel-i.

(2) Since all channels have common inlet and outlet plena, the $\Delta p_{ext,loop}$ is independent of any specific channel. Therefore, applying Eq. (2.91) to any two channels, we obtain an alternative condition,

$$\Delta p_i = \Delta p_j \text{ (for any two different channels i and j)} \tag{2.92}$$

(3) The total flow, W_{core}, entering the inlet plenum is distributed between individual channels without any mass storage. That is,

$$W_{core} = \sum_{i=1}^{N} \rho_\ell A_{xs,i}\, j_{in,i} \tag{2.93}$$

Note that the perturbation in pressure drop for the i^{th} channel, $\delta\Delta\hat{p}_i$, can be obtained from Eqs. (2.30) and (2.78) as,

$$\delta\Delta\hat{p}_i \triangleq \delta(\Delta\hat{p}_{1\phi})_i + \delta(\Delta\hat{p}_{2\phi})_i$$

$$= P_{1,i}\, \delta\hat{j}_{in,i} + \sum_{k=1}^{K_i} P^k_{2,i}\, \delta\hat{q}'''_{k,i} + P_{3,i}\, \delta\hat{h}_{in} + P_{4,i}\, \delta\hat{p} \tag{2.94}$$

where,

$$P_{1,i} = \Gamma_{1,i} + \pi_{1,i} \tag{2.95}$$

$$P^{k}_{2,i} = \begin{cases} \pi^{1\phi}_{2,i}\, H'_{k} \text{, for } k < D \\ \\ \pi^{k}_{2,i} \text{, for } k > D \end{cases} \tag{2.96}$$

$$P_{3,i} = \pi_{3,i} \tag{2.97}$$

$$P_{4,k} = \pi_{4,i} \tag{2.98}$$

The pressure drop perturbation in the external loop, $\delta\Delta\hat{p}_{ext,loop}$, will be calculated in the following sections.

2.5 Upper Plenum

The upper plenum is divided into two regions as shown in Fig. 3. In Region-I, the flow area is constant, while in Region-II it varies in the axial direction. Since the mixing in upper plenum is expected to be good, a homogeneous flow model was used in these regions. The governing equations for both regions (with flow area A(z) = constant for Region-I) are,

Mixture Continuity Equation

$$\frac{\partial\langle j\rangle}{\partial z} = v_{fg}\Gamma - \frac{\langle\alpha\rangle}{\rho_g}\frac{d\rho_g}{dt} - \langle j\rangle\frac{d(\ell nA(z))}{dz} \tag{2.99}$$

Void Propagation Equation

$$\frac{\partial\langle\alpha\rangle}{\partial t} + \langle j\rangle\frac{\partial\langle\alpha\rangle}{\partial z} = \frac{\Gamma}{\rho_g} - \frac{\langle\alpha\rangle}{\rho_g}\frac{d\rho_g}{dt} - \langle\alpha\rangle\frac{\partial\langle j\rangle}{\partial z} - \langle\alpha\rangle\langle j\rangle\frac{d(\ell nA(z))}{dz} \tag{2.100}$$

Vapor Generation Rate

$$\Gamma = \frac{1}{h_{fg}}\left[\frac{1}{J}\frac{dp}{dt} - \rho_f(1-\langle\alpha\rangle)\frac{dh_f}{dt} - \rho_g\langle\alpha\rangle\frac{dh_g}{dt}\right] \tag{2.101}$$

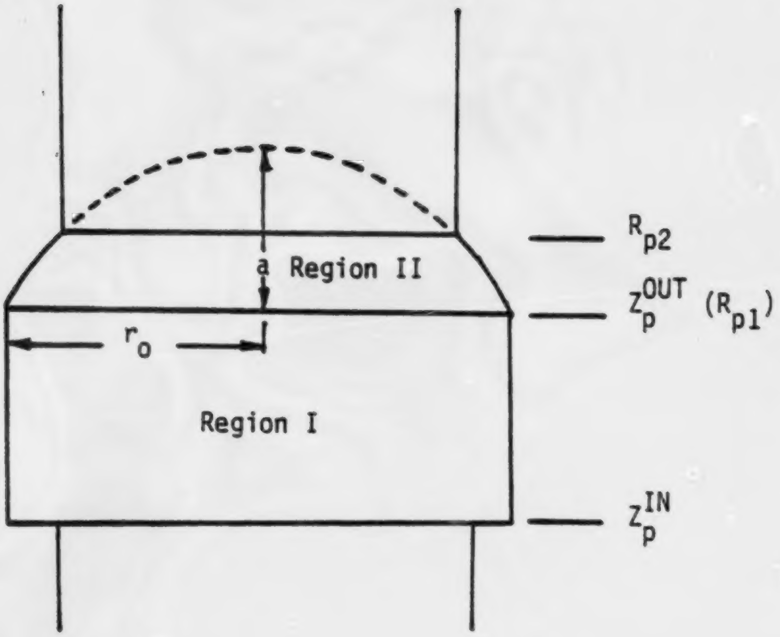
R_{p2}
a
Region II
Z_p^{OUT} (R_{p1})
r_o
Region I
Z_p^{IN}

Figure 3 Upper Plenum Geometry

Mixture Momentum Equation

$$-\frac{\partial p}{\partial z} = \frac{1}{g_c}\left[\frac{\partial[\langle\rho_H\rangle\langle j\rangle]}{\partial t} + \frac{1}{A(z)}\frac{\partial}{\partial z}\left(A(z)\langle\rho_H\rangle\langle j\rangle^2\right)\right] + \frac{f\langle\rho_H\rangle\langle j\rangle^2}{2g_c D_H} + \frac{g}{g_c}\langle\rho_H\rangle \qquad (2.102)$$

Equations (2.99)-(2.101), with $\Gamma=0$ and $d\rho_g/dt=0$, were used in the NUFREQ-N code; however, only the gravity head term in Eq. (2.102) was considered in NUFREQ-N.

The sudden area change between the boiling channels outlet and upper plenum inlet, yields complicated boundary conditions for Region-I, as shown in Appendix-G. In addition, the homogeneous flow assumption yields the following steady-state relationship,

$$\langle\alpha_p\rangle_o^{IN} = \frac{1}{\left[1 + \left(\frac{\rho_g}{\rho_f}\right)\frac{1 - \langle x_p\rangle_o^{IN}}{\langle x_p\rangle_o^{IN}}\right]} \qquad (2.103)$$

$$\langle j_p\rangle_o^{IN} = \frac{w_o}{\langle\rho_H\rangle_p^{IN} A_p} \qquad (2.104)$$

where,

$$\langle\rho_H\rangle_p^{IN} \triangleq \left(1 - \langle\alpha_p\rangle_o^{IN}\right)\rho_f + \langle\alpha_p\rangle_o^{IN}\rho_g \qquad (2.105)$$

Note that, in order to follow the notation in NUFREQ-N, the subscript "p" and "I" are used interchangeably for Region-I in this and following sections. By perturbing and Laplace transforming Eq. (2.101), we obtain,

$$\delta\hat{\Gamma}_I = \Gamma'_{UP}\,\delta\hat{p} \qquad (2.106)$$

where,

$$\Gamma'_{UP} = \frac{s}{h_{fg}}\left[\frac{1}{J} - \rho_f\left(1 - \langle\alpha_p\rangle_o^{IN}\right)\frac{dh_f}{dp} - \rho_g\langle\alpha_p\rangle_o^{IN}\frac{dh_g}{dp}\right] \qquad (2.107)$$

The term Γ'_{UP} accounts for the system pressure perturbation effect on the vapor generation rate in the upper plenum.

Perturbing, Laplace transforming Eq. (2.99) with $A(z) = A_p$ = constant, and integrating, yields,

$$\delta\langle\hat{j}_I\rangle = \delta\langle\hat{j}_p\rangle^{IN} + C_{1,UP}(z - z_p^{IN})\,\delta\hat{p} \tag{2.108}$$

where,

$$C_{1,UP} \triangleq v_{fg}\,\Gamma'_{UP} - \frac{\langle\alpha_p\rangle_o^{IN}}{\rho_g}\, s\, \frac{d\rho_g}{dp} \tag{2.109}$$

By perturbing and Laplace transforming Eq. (2.100) we obtain,

$$\frac{\partial\delta\langle\hat{\alpha}\rangle}{\partial z} + \frac{s}{\langle j_p\rangle_o^{IN}}\,\delta\langle\hat{\alpha}_I\rangle = \frac{C_{2,UP}}{\langle j_p\rangle_o^{IN}}\,\delta\hat{p} \tag{2.110}$$

where,

$$C_{2,UP} = \frac{\Gamma'_{UP}}{\rho_g} - \frac{\langle\alpha_p\rangle_o^{IN}}{\rho_g}\, s\, \frac{d\rho_g}{dp} - \langle\alpha_p\rangle_o^{IN}\, C_{1,UP} \tag{2.111}$$

Now, Eq. (2.110) can be integrated to yield,

$$\delta\langle\hat{\alpha}_I\rangle = \delta\langle\hat{\alpha}_p\rangle^{IN}\, e^{-\frac{s}{\langle j_p\rangle_o^{IN}}(z - z_p^{IN})} + \frac{C_{2,UP}}{s}\left[1 - e^{-\frac{s}{\langle j_p\rangle_o^{IN}}(z - z_p^{IN})}\right]\delta\hat{p} \tag{2.112}$$

Integrating Eq. (102), with A(z) = Ap, from $z = z_p^{IN}$ (the inlet position to Region-I) to $z = z_p^{out}$ (outlet position in Region-I), yields,

$$\Delta p = \int_{z_p^{IN}}^{z_p^{out}} \left(-\frac{\partial p}{\partial z}\right) dz \tag{2.113}$$

Due to the large cross-sectional flow area and mixing, the hydrostatic head is the dominant term in the momentum equation. Thus, the pressure drop from Eq. (2.113) is approximated as,

$$\Delta p_{UP,I} \approx \frac{g}{g_c} \int_{z_p^{IN}}^{z_p^{out}} \delta\langle\rho_H\rangle_I\, dz \tag{2.114}$$

Perturbing and Laplace transforming Eq. (2.114) with A(z) = Ap, yields,

$$\delta\Delta\hat{p}_{UP,I} = \frac{g}{g_c}\int_{z_p^{IN}}^{z_p^{out}} \delta\langle\hat{\rho}_H\rangle_I \, dz \tag{2.115}$$

where,

$$\langle\rho_H\rangle \triangleq \rho_f(1-\langle\alpha\rangle) + \rho_g\langle\alpha\rangle \tag{2.116}$$

and $\langle\alpha\rangle$ is the homogeneous void fraction. Substituting Eq. (2.112) into the perturbed and Laplaced transformed form of Eq. (2.116), we have,

$$\delta\langle\hat{\rho}_H\rangle = \Delta\rho\left(\frac{C_{2,UP}}{s}\,\delta\hat{p} - \delta\langle\hat{\alpha}_p\rangle^{IN}\right) e^{-\frac{s}{\langle j_p\rangle_o^{IN}}(z - z_p^{IN})} - \frac{\Delta\rho C_{2,UP}}{s}\,\delta\hat{p}$$
$$- \langle\alpha_p\rangle_o^{IN}\frac{d\Delta\rho}{dp}\,\delta\hat{p} \tag{2.117}$$

Consequently,

$$\int_{z_p^{IN}}^{z_p^{out}} \delta\langle\hat{\rho}_H\rangle \, dz = \frac{\langle j_p\rangle_o^{IN}}{s}\,\Delta\rho\left(\frac{C_{2,UP}}{s}\,\delta\hat{p} - \delta\langle\hat{\alpha}_p\rangle^{IN}\right)\left[1 - e^{-\frac{s}{\langle j_p\rangle_o^{IN}}\Delta z_p}\right]$$
$$- \delta\hat{p}\left(\langle\alpha_p\rangle_o^{IN}\frac{d\Delta\rho}{dp} + \frac{\Delta\rho(C_{2,UP})}{s}\right)\Delta z_p \tag{2.118}$$

where,

$$\Delta z_p \triangleq z_p^{OUT} - z_p^{IN} \tag{2.119}$$

Integrating Eq. (2.108) from $z = z_p^{IN}$ to $z = z_p^{OUT}$ yields,

$$\int_{z_p^{IN}}^{z_p^{OUT}} \delta\langle\hat{j}_I\rangle \, dz = \delta\langle\hat{j}_p\rangle^{IN}\,\Delta z_p + \frac{1}{2}\,C_{1,UP}\,(\Delta z_p)^2\,\delta\hat{p} \tag{2.120}$$

Using Eq. (2.108), we obtain,

$$\delta\langle\hat{j}_p\rangle^{OUT} = \delta\langle\hat{j}\rangle_p^{IN} + C_{1,Up}\,\Delta z_p\,\delta\hat{p} \tag{2.121}$$

By Eqs. (2.116) and (2.112), we have,

$$\delta\langle\hat{\rho}_H\rangle_p^{IN} = - \Delta\rho\delta\langle\hat{\alpha}_p\rangle^{IN} - \langle\alpha_p\rangle_o^{IN} \frac{d\Delta\rho}{dp} \delta\hat{p} \tag{2.122}$$

$$\delta\langle\hat{\rho}_H\rangle_p^{OUT} = - \Delta\rho \left[\delta\langle\hat{\alpha}_p\rangle^{IN} - e^{-\frac{s\Delta z_p}{\langle j_p\rangle_o^{IN}}} + \frac{C_{2,UP}}{s}\left(1 - e^{-\frac{s\Delta z_p}{\langle j_p\rangle_o^{IN}}}\right) \delta\hat{p}\right]$$

$$- \langle\alpha_p\rangle_o^{IN} \frac{d\Delta\rho}{dp} \delta\hat{p} \tag{2.123}$$

Substituting Eqs. (2.116)-(2.123) into Eq. (2.115) yields,

$$\delta(\Delta\hat{p})_{UP,I} = \frac{1}{g_c} A_{J,UP,I}\ \delta\langle\hat{j}_p\rangle^{IN} + \frac{1}{g_c} A_{\alpha,UP,I}\ \delta\langle\hat{\alpha}_p\rangle^{IN} + \frac{1}{g_c} A_{p,UP,I}\ \delta\hat{p} \tag{2.124}$$

where,

$$A_{J,UP,I} \triangleq 0 \tag{2.125}$$

$$A_{\alpha,UP,I} \triangleq - \frac{g\langle j_p\rangle_o^{IN}\ \Delta\rho}{s}\left(1 - e^{-\frac{s}{\langle j_p\rangle_o^{IN}}\Delta z_p}\right) \tag{2.126}$$

$$A_{p,UP,I} = g\left[\frac{\langle j_p\rangle_o^{IN}\ \Delta\rho\ C_2}{s^2}\left(1 - e^{-\frac{s}{\langle j_p\rangle_o^{IN}}\Delta z_p}\right) + \left(- \langle\alpha_p\rangle_o^{IN} \frac{d\Delta\rho}{dp}\right.\right.$$

$$\left.\left. - \frac{\Delta\rho C_{2,UP}}{s}\right) \Delta z_p\right] \tag{2.127}$$

In Region-II, the cross sectional area is assumed to be in the form of a chopped hemisphere, as shown schematically in Fig. 3.

Consequently, the flow area at position Z is given as,

$$A(z) = \pi[r_o^2 - (z - R_{p1})^2] + \pi\left(a - \frac{r_o^2}{a}\right)(z - R_{p1}) \tag{2.128}$$

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The inlet conditions for Region-II are given as,

$$\langle j_{II}\rangle\Big|_{z=R_{p1}} = \langle j_I\rangle\Big|_{z=R_{p1}} \tag{2.129}$$

$$\langle \alpha_{II}\rangle\Big|_{z=R_{p1}} = \langle \alpha_I\rangle\Big|_{z=R_{p1}} \tag{2.130}$$

First, consider the steady-state form of Eq. (2.99)-(2.101). From Eq. (2.101), we have

$$\Gamma_{II,0} = 0 \tag{2.131}$$

Substituting Eq. (2.131) into Eqs. (2.99) and (2.100), respectively, yields,

$$\langle j_{II}(z)\rangle_o = \frac{A(R_{p1})}{A(z)}\langle j_I(R_{p1})\rangle_0 = \frac{A_p}{A(z)}\langle j_p\rangle_o^{IN} \tag{2.132}$$

and,

$$\langle \alpha_{II}(z)\rangle_o = \langle \alpha_I(R_{p1})\rangle_o = \langle \alpha_p\rangle^{IN} \tag{2.133}$$

For the transient analysis, we can perturb and Laplace trnasform Eq. (2.101) to obtain,

$$\delta\hat{\Gamma}_{II} = \frac{s}{h_{fg}}\left[\frac{1}{J} - \rho_f(1-\langle\alpha_{II}\rangle_o)\frac{dh_f}{dp} - \rho_g\langle\alpha_{II}\rangle_o\frac{dh_g}{dp}\right] = \Gamma'_{UP}\,\delta\hat{p} \tag{2.134}$$

Similarly, Eq. (2.99) and (2.100), respectively, yield,

$$\delta\langle\hat{j}_{II}(z)\rangle = \frac{Ap}{A(z)}\,\delta\langle\hat{j}_{II}(R_{p1})\rangle + \frac{V(z)}{A(z)}\,C_{1,UP}\,\delta\hat{p} \tag{2.135}$$

and,

$$\delta\langle\hat{\alpha}_{II}\rangle = \delta\langle\hat{\alpha}_I(R_{p1})\rangle\, e^{-\frac{sV(z)}{\langle j_p\rangle_o^{IN} Ap}} + \frac{C_{2,UP}}{s}\left(1 - e^{-\frac{sV(z)}{\langle j_p\rangle_o^{IN} Ap}}\right)\delta\hat{p} \tag{2.136}$$

where,

$$V(z) \triangleq \int_{R_{p1}}^{z} A(z')\,dz' = A_p(z - R_{p1}) - \frac{\pi}{3}(z - R_{p1})^3 + \pi\left(a - \frac{r_o^2}{a}\right)\frac{(z-R_{p1})^2}{2} \tag{2.137}$$

Similarly, the pressure drop in this region is also approximated as,

$$\Delta p_{UP,II} \approx \frac{g}{g_c} \int_{R_{p1}}^{R_{p2}} \langle \rho_H \rangle_{II} \, dz \tag{2.138}$$

where,

$$\langle \rho_H \rangle_{II} \triangleq \rho_f (1 - \langle \alpha_{II} \rangle) + \rho_g \langle \alpha_{II} \rangle \tag{2.139}$$

By perturbing and Laplace transforming Eq. (2.138), we obtain,

$$\delta \langle \hat{\rho}_H \rangle_{II} = - \langle \alpha_p \rangle_o \frac{d\Delta\rho}{dp} \delta\hat{p} - \Delta\rho \, \delta \langle \hat{\alpha}_{II} \rangle = \left(- \langle \alpha_p \rangle_o \frac{d\Delta\rho}{dp} - \frac{C_{2,UP} \, \Delta\rho}{s} \right) \delta\hat{p}$$

$$- \Delta\rho \left(\delta \langle \hat{\alpha}_I (R_{p1}) \rangle - \frac{C_{2,UP}}{s} \delta\hat{p} \right) e^{- \frac{sV(z)}{\langle j_p \rangle_o^{IN} Ap}} \tag{2.140}$$

Substituting Eq. (2.140) into the perturbed and Laplace-transformed form of Eq. (2.138), and integrating, yields,

$$\delta (\Delta\hat{p})_{UP,II} = \frac{1}{g_c} A_1 \, \delta \langle \hat{\alpha}_I (R_{p1}) \rangle + \frac{1}{g_c} A_2 \, \delta\hat{p} \tag{2.141}$$

where,

$$A_1 = - g \, \Delta\rho \, F = - g \frac{\Delta\rho \langle j_p \rangle_o^{IN}}{s} \left(1 - e^{- \frac{s}{\langle j_p \rangle_o^{IN}} \Delta L_p} \right) \tag{2.142}$$

$$A_2 = g \left(- \langle \alpha_p \rangle_o^{IN} \frac{d\Delta\rho}{dp} - \frac{C_{2,UP} \Delta\rho}{s} \right) \Delta L_p + g\Delta\rho \frac{C_{2,UP} \langle j_p \rangle_o^{IN}}{s^2} \left(1 - e^{- \frac{s}{\langle j_p \rangle_o^{IN}} \Delta L_p} \right) \tag{2.143}$$

$$F \triangleq \int_{R_{p1}}^{R_{p2}} \exp \left(- \frac{sV(z')}{\langle j_p \rangle_o^{IN} Ap} \right) dz' \approx \frac{\langle j_p \rangle_o^{IN}}{s} \left\{ 1 - \exp \left[- \frac{s}{\langle j_p \rangle_o^{IN}} (R_{p2} - R_{p1}) \right] \right\} \tag{2.144}$$

Using Eq. (2.112), Eq. (2.141) becomes,

$$\delta(\Delta\hat{p})_{UP,II} = \frac{1}{g_c} A_{\alpha,UP,II}\, \delta\langle\hat{\alpha}_p\rangle^{IN} + \frac{1}{g_c} A_{p,UP,II}\, \delta\hat{p} \qquad (2.145)$$

where,

$$A_{\alpha,UP,II} \triangleq A_1\, e^{-\frac{s}{\langle j_p\rangle_o^{IN}} \Delta z_p} \qquad (2.146)$$

$$A_{p,UP,II} \triangleq A_1 \frac{C_{2,UP}}{s}\left(1 - e^{-\frac{s}{\langle j_p\rangle_o^{IN}} \Delta z_p}\right) + A_2 \qquad (2.147)$$

$$\Delta z_p \triangleq R_{p1} - z_p^{IN} = z_p^{OUT} - z_p^{IN} \qquad (2.148)$$

By combining Eq. (2.124) with Eq. (2.145), the total pressure drop perturbation across the upper plenum is obtained as,

$$\delta(\Delta\hat{p})_{UP} \triangleq \delta(\Delta\hat{p})_{UP,I} + \delta(\Delta\hat{p})_{UP,II} = \frac{1}{g_c} A_{J,UP}\, \delta\langle\hat{j}_p\rangle^{IN} + \frac{1}{g_c} A_{\alpha,UP}\, \delta\langle\hat{\alpha}_p\rangle^{IN}$$

$$+ \frac{1}{g_c} A_{p,UP}\, \delta\hat{p} \qquad (2.149)$$

where,

$$A_{J,UP} \triangleq A_{J,UP,I} \qquad (2.150)$$

$$A_{\alpha,UP} \triangleq A_{\alpha,UP,I} + A_{\alpha,UP,II} \qquad (2.151)$$

$$A_{p,UP} \triangleq A_{p,UP,I} + A_{p,UP,II} \qquad (2.152)$$

Substituting Eqs. (G-23) and (G-33) into Eq. (2.149), we obtain,

$$\delta(\Delta\hat{p})_{UP} = \sum_{j=1}^{N} UP'_{J,j}\, \delta\langle\hat{j}\rangle_j^{OUT} + \sum_{j=1}^{N} UP'_{\alpha,j}\, \delta\langle\hat{\alpha}\rangle_j^{OUT} + UP'_p\, \delta\hat{p} \qquad (2.153)$$

where,

$$UP'_{J,j} \triangleq \frac{1}{g_c}\left(A_{J,UP}\, J_{1,j} + A_{\alpha,UP}\, F_{1,j}\right) + UP'_{w,j}\, A_{xs,j}\, \rho'_j \tag{2.154}$$

$$UP'_{\alpha,j} \triangleq \frac{1}{g_c}\left(A_{J,UP}\, J_{2,j} + A_{\alpha,UP}\, F_{2,j}\right) - UP'_{w,j}\, A_{xs,j}\, g'_j \tag{2.155}$$

$$UP'_{w,j} \triangleq \frac{1}{g_c}\left(A_{J,UP}\, J_{3,j} + A_{\alpha,UP}\, F_{3,j}\right) \tag{2.156}$$

$$UP'_p \triangleq \frac{1}{g_c}\left(A_{J,UP}\, J_4 + A_{\alpha,UP}\, F_4 + A_{p,UP}\right) + \sum_{j=1}^{N} UP'_{w,j}\, A_{xs,j}\, g_{p,j} \tag{2.157}$$

where ρ'_j, g'_j, and $g_{p,j}$ are defined in Eqs. (G-40), (G-55), and (G-56).

Since Eqs. (B-151) and (B-152) yield,

$$\delta\langle\hat{j}\rangle_j^{OUT} = B_{1,N_j,j}\, \delta\hat{j}_{in,j} + B^{1\phi}_{2,N_j,j} \sum_{\ell}^{L_j} H'_{\ell j}\, \delta\hat{q}'''_{\ell,j} + \sum_{i=D}^{K_j} B^{i}_{2,N_j,j}\, \delta\hat{q}'''_{i,j} + B_{3,N_j,j}\, \delta\hat{h}_{in} + B_{4,N_j,j}\, \delta\hat{p} \tag{2.158}$$

and,

$$\delta\langle\hat{\alpha}\rangle_j^{OUT} = K_{1,N_j,j}\, \delta\hat{j}_{in,j} + K^{1\phi}_{2,N_j,j} \sum_{\ell}^{L_j} H'_{\ell j}\, \delta\hat{q}'''_{\ell,j} + \sum_{i=D}^{K_j} K^{i}_{2,N_j,j}\, \delta\hat{q}'''_{i,j} + K_{3,N_j,j}\, \delta\hat{h}_{in} + K_{4,N_j,j}\, \delta\hat{p} \tag{2.159}$$

and also,

$$\delta\hat{w}_j^{OUT} = A_{xs,j}\, \delta\hat{G}_j^{OUT} = A_{xs,j}\left(\rho'_j\, \delta\langle\hat{j}\rangle_j^{OUT} - g'_j\, \delta\langle\hat{\alpha}\rangle_j^{OUT} + g_{p,j}\, \delta\hat{p}\right) \tag{2.160}$$

then Eq. (2.153) finally becomes,

$$\delta(\Delta\hat{p})_{UP} = \sum_{j=1}^{N} UP_{J,j}\ \delta\hat{j}_{in,j} + \sum_{j=1}^{N} UP^{1\phi}_{q,j} \sum_{\ell}^{L_j} H'_{\ell,j}\ \delta\hat{q}'''_{\ell,j} + \sum_{j=1}^{N} \sum_{i=D}^{K_j} UP^{i}_{q,j}\ \delta\hat{q}'''_{i,j}$$

$$+ UP_h\ \delta\hat{h}_{in} + UP_p\ \delta\hat{p} \qquad (2.161)$$

Where,

$$UP_{J,j} \triangleq UP'_{J,j}\ B_{1,Nj,j} + UP'_{\alpha,j}\ K_{1,Nj,j} \qquad (2.162)$$

$$UP^{1\phi}_{q,j} \triangleq UP'_{J,j} + B^{1\phi}_{2,Nj,j} + UP'_{\alpha,j}\ K^{1\phi}_{2,Nj,j} \qquad (2.163)$$

$$UP^{i}_{q,Nj,j} \triangleq UP'_{J,j}\ B^{i}_{2,Nj,j} + UP'_{\alpha,j}\ K^{i}_{2,Nj,j} \qquad (2.164)$$

$$UP_h \triangleq \sum_{j=1}^{N} [UP'_{J,j}\ B_{3,Nj,j} + UP'_{\alpha,j}\ K_{3,Nj,j}] \qquad (2.165)$$

$$UP_p \triangleq \sum_{j=1}^{N} [UP'_{J,j}\ B_{4,Nj,j} + UP'_{\alpha,j}\ K_{4,Nj,j}] + UP'_p \qquad (2.166)$$

2.6 Riser

The riser model accounts for the standpipes. It is characterized by and equivalent line to simulate the various parallel paths. The same procedure is used for all other parallel lines in the recirculation loop. Since the riser is relatively long, the two-phase flow in it will exhibit phasic slip. The governing equations are,

Mixture Continuity Equation

$$\frac{\partial\langle j_R\rangle}{\partial z} = v_{fg}\ \Gamma_R - \frac{\langle\alpha_R\rangle}{\rho_g}\frac{d\rho_g}{dt} \qquad (2.167)$$

Void Propagation Equation

$$\frac{\partial\langle\alpha_R\rangle}{\partial t} + C_{K,R}\frac{\partial\langle\alpha_R\rangle}{\partial z} = \frac{\Gamma_R}{\rho_g} - \frac{\langle\alpha_R\rangle}{\rho_g}\frac{d\rho_g}{dt} - \langle\alpha_R\rangle C_{o,R}\frac{\partial\langle j_R\rangle}{\partial z} \qquad (2.168)$$

Vapor Generation Rate

$$\Gamma_R = \frac{1}{h_{fg}}\left[\frac{1}{J}\frac{dp}{dt} - \rho_f(1-\langle\alpha_R\rangle)\frac{dh_f}{dt} - \rho_g\langle\alpha_R\rangle\frac{dh_g}{dt}\right] \qquad (2.169)$$

Mixture Momentum Equation

$$-\frac{\partial p}{\partial z} = \frac{1}{g_c}\left(\frac{\partial G}{\partial t} + \frac{\partial G'}{\partial z}\right) + \frac{1}{g_c}\frac{\partial}{\partial z}S_{DG} + \frac{g}{g_c}\langle\bar{\rho}\rangle + \frac{fG^2}{2g_c\rho_f D_H}\phi_{\ell o}^2$$

$$+ K_{in}\frac{G^2\Phi}{2g_c\rho_f}\delta(z - R_{p2}) + K_{exit}\frac{G^2\Phi}{2g_c\rho_f}\delta(z - L_R) \qquad (2.170)$$

The expressions for G', S_{DG}, and $\langle\bar{\rho}\rangle$ are given by Eqs. (2.44)-(2.47).

Since an abrupt change in the flow structure is assumed to occur at the junction between the exit of the upper plenum and the inlet to the riser, the inlet flow conditions are calculated in a similar fashion as those of section 2.5. The details are shown in Appendix H. Some of the useful steady-state relationships are,

$$\langle j_R(z)\rangle_o = \langle j_R\rangle_o^{in} \qquad (2.171)$$

$$C_{K,R,o} = C_{o,R}\langle j_R\rangle_o^{in} + V_{gj,R} \qquad (2.172)$$

$$\langle\alpha_R(z)\rangle_o = \langle\alpha_R\rangle_o^{in} \qquad (2.173)$$

$$\langle\bar{\rho}_R\rangle_o = \rho_f(1-\langle\alpha_R\rangle_o^{in}) + \rho_g\langle\alpha_R\rangle_o^{in} \qquad (2.174)$$

$$G_{o,R} = (\rho_f - \Delta\rho C_{o,R}\langle\alpha_R\rangle_o^{in})\langle j_R\rangle_o^{in} - \Delta\rho V_{gj,R}\langle\alpha_R\rangle_o^{in} \qquad (2.175)$$

$$\Delta p_{R,o} = \left(\frac{fG_{o,R}^{2}\ \phi_{\ell o}^{2}}{2g_c\ D_H\ \rho_f} + \frac{g}{g_c}\ \langle\bar{\rho}_R\rangle_o\right)\ \Delta z_R + \frac{G_{o,R}^{2}\ \Phi}{2g_c\ \rho_f}\left(K_{in} + K_{exit}\right) \tag{2.176}$$

Perturbing and Laplace transforming Eqs. (2.169) and (2.167), respectively, yields,

$$\delta\hat{\Gamma}_R = \frac{s}{h_{fg}}\left[\frac{1}{J} - \rho\ \left(1-\langle\alpha_R\rangle_o^{IN}\right)\frac{dh_f}{dp} - \rho_g\langle\alpha_R\rangle_o^{IN}\frac{dh_g}{dp}\right]\ \delta\hat{p} \triangleq \Gamma_R'\ \delta\hat{p} \tag{2.177}$$

and,

$$\frac{\partial\delta\langle\hat{j}_R\rangle}{\partial z} = C_{1,R}\ \delta\hat{p} \tag{2.178}$$

where,

$$C_{1,R} = v_{fg}\ \Gamma_R' - \frac{\langle\alpha_R\rangle_o^{IN}}{\rho_g}\ s\ \frac{d\rho_g}{dp} \tag{2.179}$$

Equation (2.178) can be integrated to obtain,

$$\delta\langle\hat{j}_R\rangle = \delta\langle\hat{j}_R\rangle^{in} + C_{1,R}(z - R_{p2})\ \delta\hat{p} \tag{2.180}$$

Perturbing and Laplace transforming Eq. (2.168) yields,

$$\frac{\partial\delta\langle\hat{\alpha}_R\rangle}{\partial z} + \frac{s}{C_{K,R,o}}\ \delta\langle\hat{\alpha}\rangle_R = \frac{C_{2,R}}{C_{K,R,o}}\ \delta\hat{p} \tag{2.181}$$

where,

$$C_{2,R} \triangleq \frac{1}{\rho_g}\ \Gamma_R' - \frac{\langle\alpha_R\rangle_o^{IN}}{\rho_g}\ s\ \frac{d\rho_g}{dp} - \langle\alpha_R\rangle_o^{IN}\ C_{o,R}\ C_{1,R} \tag{2.182}$$

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After integrating Eq. (2.181), we obtain,

$$\delta\langle\hat{\alpha}_R\rangle = \delta\langle\hat{\alpha}_R\rangle^{IN} e^{-\frac{s}{C_{K,R,o}}(Z-R_{p2})} + \frac{C_{2,R}}{s}\left[1 - e^{-\frac{s}{C_{K,R,o}}(z-R_{p2})}\right]\delta\hat{p} \qquad (2.183)$$

The expressions for $\langle j_R\rangle_o^{IN}$, $\langle\alpha_R\rangle_o^{IN}$, $\delta\langle\hat{j}_R\rangle^{IN}$ and $\delta\langle\hat{\alpha}_R\rangle^{IN}$ are derived in Appendix-H.

The pressure drop perturbation in the riser is given by Eq. (2.170) as,

$$\delta\Delta\hat{p}_R \triangleq -\int_{R_{p2}}^{L_R} \frac{\partial\delta\hat{p}}{\partial z}\,dz$$

$$= \frac{1}{g_c}\int_{R_{p2}}^{L_R}\left[s\delta\hat{G} + \frac{\partial}{\partial z}\delta\hat{G}' + \frac{\partial}{\partial z}\delta\hat{S}_{DG} + g\delta\langle\hat{\bar{\rho}}\rangle + \frac{fG_{o,R}^2}{2D_H\rho_f}\delta\hat{\phi}_{\ell o}^2 + \frac{fG_{o,R}\phi_{\ell o}^2}{D_H\rho_f}\delta\hat{G}\right]dz$$

$$+ K_{in}\left\{\frac{G_{o,R}\Phi_o}{g_c\rho_f}\delta\hat{G}\Big|_{z=R_{p2}} + \frac{G_{o,R}^2}{2g_c\rho_f}\delta\hat{\Phi}\Big|_{z=R_{p2}}\right\}$$

$$+ K_{exit}\left\{\frac{G_{o,R}\Phi_o}{g_c\rho_f}\delta\hat{G}\Big|_{z=L_R} + \frac{G_{o,R}^2}{2g_c\rho_f}\delta\hat{\Phi}\Big|_{z=L_R}\right\} \qquad (2.184)$$

After substituting Eqs. (2.180) and (2.183) into Eq. (2.184) and performing the integration, we obtain,

$$\delta(\Delta\hat{p})_R = \frac{1}{g_c}A'_{J,R}\,\delta\langle\hat{j}_R\rangle^{in} + \frac{1}{g_c}A'_{\alpha,R}\,\delta\langle\hat{\alpha}_R\rangle^{in} + \frac{1}{g_c}A'_{p,R}\,\delta\hat{p} \qquad (2.185)$$

where,

$$A'_{J,R} \triangleq \left(s\rho' + \frac{fG_o\phi_{\ell o}^2\rho'}{D_H\rho_f} + \frac{fC}{2D_H}\Delta G\right)\Delta z_R + \left(K_{in} + K_{exit}\right)\left(G_o\frac{\Phi\rho'}{\rho_f} + \frac{C}{2}\Delta G\right) \qquad (2.186)$$

$$A'_{\alpha,R} \triangleq (e^{-\frac{s\Delta z_R}{C_{K,R,o}}} - 1) \{\frac{C_{K,R,o}\Delta\rho}{s} [g + \frac{fC_{k,R,0}}{2D_H} (\frac{2G_o\phi^2_{\ell o}}{\rho_f} - C\langle j_R\rangle_o)]$$

$$+ \Delta\rho(\overline{V}'_1 + \frac{G_o^2}{\langle\bar{\rho}\rangle^2} - \frac{2G_oC_{K,R,c}}{\langle\bar{\rho}\rangle}) - \frac{1}{2}\Delta\rho\, C_{K,o}(K_{in} + K_{exit}\, e^{-\frac{s\Delta z_R}{C_{K,R,o}}}) \cdot$$

$$(\frac{2G_o\Phi}{\rho_f} - C\langle j_R\rangle_o) \tag{2.187}$$

$$A'_{\rho,R} \triangleq [g + \frac{fC_{K,R,o}}{2D_H} (\frac{2G_o\phi^2_{\ell o}}{\rho_f} - C\langle j_R\rangle_o) + sV_{gj,R} + \frac{s}{C_{K,R,o}} (\frac{G_o^2}{\langle\bar{\rho}\rangle^2} - \frac{2G_oC_{K,R,o}}{\langle\bar{\rho}\rangle})]$$

$$\frac{\Delta\rho\; C_{2,R}\; C_{k,R,o}}{s^2} (1 - e^{-\frac{s\Delta z_R}{C_{K,R,o}}}) + \frac{\overline{V}'_1\Delta\rho\; C_{2,R}}{s}(1 - e^{-\frac{s\Delta z_R}{C_{K,o}}})$$

$$+ \Delta z_R\; [s + \frac{f}{2D_H}(\frac{2G_o\phi^2_{\ell o}}{\rho_f} - C\langle j_R\rangle_o)]\; (g_p - \frac{\Delta\rho C_{K,R,o}C_{2,R}}{s} + \frac{\rho' C_{1,R}\Delta z_R}{s})$$

$$+ g\; (- \frac{\Delta\rho C_{2,R}}{s} - \langle\alpha_R\rangle_o \frac{d\Delta\rho}{dp})\; \Delta z_R + \frac{2G_oC_{1,R}\Delta z_R}{\langle\bar{\rho}\rangle}\rho' + 2\overline{V}'_2\; C_{1,R}\; \Delta z_R$$

$$+ \frac{CfG_o^2(\Delta z_R)^2\; C_{1,R}}{4D_H\; G_o}) + K_{in}C_{R,6} + K_{exit}C^{*}_{R,6} \tag{2.188}$$

$$\rho' = \rho_f - \Delta\rho\; C_{o,R}\; \langle\alpha_R\rangle_o^{IN} \tag{2.189}$$

$$\Delta G = G_o - \rho'\langle j_R\rangle_o = - \Delta\rho\; V_{gj,R}\; \langle\alpha_R\rangle_o^{IN} \tag{2.190}$$

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$$g_p \triangleq -\frac{d\Delta\rho}{dp}\langle\alpha_R\rangle_o C_{K,R,o} - \langle\alpha_R\rangle_o \Delta\rho \left(\frac{dC_o}{dp}\langle j_R\rangle_o + \frac{dV_{gj}}{dp}\right) \tag{2.191}$$

$$\overline{V}_1' \triangleq \frac{\rho_f\rho_g V_{gj}'^{2}}{(\langle\bar{\rho}\rangle^2 - \rho_g\langle\bar{\rho}\rangle)^2}\{2\rho_f\langle\bar{\rho}\rangle - \langle\bar{\rho}\rangle^2 - \rho_f\rho_g\} \tag{2.192}$$

$$\overline{V}_2' \triangleq \frac{\rho_f - \langle\bar{\rho}\rangle}{\langle\bar{\rho}\rangle - \rho_g}\cdot\frac{\rho_f\rho_g}{\langle\bar{\rho}\rangle} V_{gj}' \tag{2.193}$$

$$C_{R,6} \triangleq g_p\left(\frac{G_o\Phi}{g_c\rho_f} - \frac{C\langle j_R\rangle_o}{2g_c}\right) \tag{2.194}$$

$$C_{R,6}^* \triangleq g_p^*\left(\frac{G_o\Phi}{g_c\rho_f} - \frac{C\langle j_R\rangle_o}{2g_c}\right) \tag{2.195}$$

$$g_p^* \triangleq \rho' C_{1,R}\Delta z_R - \Delta\rho C_{K,R,o}\frac{C_{2,R}}{s}\left(1 - e^{-\frac{S\Delta z_R}{C_{K,R,o}}}\right) + g_p \tag{2.196}$$

Furthermore, using Eqs. (H-30) and (H-31) for $\delta\langle\hat{j}_R\rangle^{in}$ and $\delta\langle\hat{\alpha}_R\rangle^{in}$, respectively, we obtain,

$$\delta(\Delta\hat{p})_R = \frac{1}{g_c}A''_{J,R}\,\delta\langle\hat{j}_I\rangle^{OUT} + \frac{1}{g_c}A''_{\alpha,R}\,\delta\langle\hat{\alpha}_I\rangle^{OUT} + \frac{1}{g_c}A''_{p,R}\,\delta\hat{p} \tag{2.197}$$

where,

$$A''_{J,R} \triangleq A'_{J,R}J_{1,R} + A'_{\alpha,R}K_{1,R} \tag{2.198}$$

$$A''_{\alpha,R} \triangleq A'_{J,R}J_{2,R} + A'_{\alpha,R}K_{2,R} \tag{2.199}$$

$$A''_{p,R} \triangleq A'_{J,R} \, J_{3,R} + A'_{\alpha,R} \, K_{3,R} + A'_{p,R} \tag{2.200}$$

Using Eqs. (2.108) and (2.112), Eq. (2.197) becomes

$$\delta(\Delta\hat{p})_R = \frac{1}{g_c} A_{J,R} \, \delta\langle\hat{j}_p\rangle^{IN} + \frac{1}{g_c} A_{\alpha,R} \, \delta\langle\hat{\alpha}_p\rangle^{IN} + \frac{1}{g_c} A_{p,R} \, \delta\hat{p} \tag{2.201}$$

where,

$$A_{J,R} \triangleq A''_{J,R} \tag{2.202}$$

$$A_{\alpha,R} \triangleq A''_{\alpha,R} \, e^{-\frac{s\Delta z_p}{\langle j_p\rangle_o^{IN}}} \tag{2.203}$$

$$A_{p,R} \triangleq A''_{p,R} + A''_{J,R} \, C_{1,R} \, \Delta z_p + A''_{\alpha,R} \, \frac{C_{2,UP}}{s} \left(1 - e^{-\frac{s\Delta z_p}{\langle j_p\rangle_o^{IN}}}\right) \tag{2.204}$$

Substituting Eqs. (G-23) and (G-33) into Eq. (2.201) and rearranging, yields,

$$\delta(\Delta\hat{p})_R = \sum_{j=1}^{N} R'_{J,j} \, \delta\langle\hat{j}\rangle_j^{OUT} + \sum_{j=1}^{N} R'_{\alpha,j} \, \delta\langle\hat{\alpha}\rangle_j^{OUT} + \sum_{j=1}^{N} R'_{w,j} \, \delta\hat{w}_j^{OUT} + R'_p \, \delta\hat{p} \tag{2.205}$$

where,

$$R'_{J,j} \triangleq \frac{1}{g_c}\left(A_{J,R} \, J_{1,j} + A_{\alpha,R} \, F_{1,j}\right) \tag{2.206}$$

$$R'_{\alpha,j} \triangleq \frac{1}{g_c}\left(A_{J,R} \, J_{2,j} + A_{\alpha,R} \, F_{2,j}\right) \tag{2.207}$$

$$R'_{w,j} \triangleq \frac{1}{g_c}\left(A_{J,R} \, J_{3,j} + A_{\alpha,R} \, F_{3,j}\right) \tag{2.208}$$

$$R'_p \triangleq \frac{1}{g_c}\left(A_{J,R} \, J_4 + A_{\alpha,R} \, F_4 + A_{p,R}\right) \tag{2.209}$$

Finally, using Eqs. (2.158), (2.159) and (2.160), Eq. (2.205) becomes

$$\delta(\Delta\hat{p})_R = \sum_{j=1}^{N} R_{J,j}\ \delta\hat{j}_{in,j} + \sum_{j=1}^{N} R^{1\phi}_{q,j} \sum_{\ell}^{L_j} H'_{\ell,j}\ \delta\hat{q}'''_{\ell,j} + \sum_{j=1}^{N} \sum_{i=D}^{K_j} R^{i}_{q,j}\ \delta\hat{q}'''_{i,j}$$

$$+ R_h\ \delta\hat{h}_{in} + R_p\ \delta\hat{p} \qquad (2.210)$$

where,

$$R_{J,j} \triangleq (R'_{J,j} + R'_{w,j}\ \rho_f\ A_{xs,j})\ B_{1,Nj,j} + R'_{\alpha,j}\ K_{1,Nj,j} \qquad (2.211)$$

$$R^{1\phi}_{q,j} \triangleq (R'_{J,j} + R'_{w,j}\ \rho_f\ A_{xs,j})\ B^{1\phi}_{1,Nj,j} + R'_{\alpha,j}\ K^{1\phi}_{2,Nj,j} \qquad (2.212)$$

$$R^{i}_{q,j} \triangleq (R'_{J,j} + R'_{w,j}\ \rho_f\ A_{xs,j})\ B^{i}_{2,Nj,j} + R'_{\alpha,j}\ K^{i}_{2,Nj,j} \qquad (2.213)$$

$$R_h \triangleq \sum_{j=1}^{N} [(R'_{J,j} + R'_{w,j}\ \rho_f\ A_{xs,j})\ B_{3,Nj,j} + R'_{\alpha,j}\ K_{3,Nj,j}] \qquad (2.214)$$

$$R_p \triangleq \sum_{j=1}^{N} [(R'_{J,j} + R'_{w,j}\ \rho_f\ A_{xs,j})\ B_{4,Nj,j} + R'_{\alpha,j}\ K_{4,Nj,j}] + R'_p \qquad (2.215)$$

In order to connect the steam separator model with that of the recirculation loop, the perturbation in the saturated water flow rate, w_{SW}, must be evaluated.

Expressing w_{SW} in terms of the flow parameters at the riser outlet,

$$w_{SW} = w_R(1 - \langle x\rangle^{OUT}_R) \qquad (2.216)$$

and perturbing, we obtain,

$$\delta\hat{w}_{SW} = -\ w_{R,o}\ \delta\langle\hat{x}\rangle^{OUT}_R + (1 - \langle x_o\rangle^{OUT}_R)\ A_R\ \delta\hat{G}^{OUT}_R \qquad (2.217)$$

The steam quality perturbation, $\delta\langle\hat{x}\rangle_R^{OUT}$ can be obtained from Eq. (F-28) as,

$$\delta\langle\hat{x}\rangle_R^{OUT} = \frac{1}{v_{fg}G_{R,o}}\,\delta\langle\hat{j}\rangle_R^{OUT} - \frac{\langle j_o\rangle_R}{v_{fg}G_{R,o}^2}\,\delta\hat{G}_R^{OUT} + Sp\;\delta\hat{p} \tag{2.218}$$

where,

$$Sp \triangleq \frac{1}{\Delta\rho}\frac{d\rho_g}{dp} - \frac{\rho_g}{\Delta\rho^2}\frac{d\Delta\rho}{dp} + \frac{\langle j_o\rangle_R}{v_{fg}^2 G_{R,o}}\frac{dv_{fg}}{dp} \tag{2.219}$$

The mass flux perturbation, $\delta\hat{G}_R^{OUT}$, can also be obtained from Eq. (F-6) as,

$$\delta\hat{G}_R^{OUT} = g_1\;\delta\langle\hat{j}\rangle_R^{OUT} + g_2\;\delta\langle\hat{\alpha}\rangle_R^{OUT} + g_3\;\delta\hat{p} \tag{2.220}$$

where,

$$g_1 = \rho_f - \Delta\rho\;C_{o,R}\;\langle\alpha_R\rangle_o^{IN} \tag{2.221}$$

$$g_2 = -\,\Delta\rho\;C_{K,R,o} \tag{2.222}$$

$$g_3 = -\,\langle\alpha_R\rangle_o\;C_{K,R,o}\,\frac{d\Delta\rho}{dp} - \langle\alpha_R\rangle_o\;\Delta\rho\;\left(\langle j_R\rangle_o\,\frac{dC_o}{dp} + \frac{dV_{gj}}{dp}\right) \tag{2.223}$$

Substituting Eqs. (2.218) and (2.220) into Eq. (2.217), yields,

$$\delta\hat{w}_{SW} = L_1'\;\delta\langle\hat{j}\rangle_R^{OUT} + L_2'\;\delta\langle\hat{\alpha}\rangle_R^{OUT} + L_3'\;\delta\hat{p} \tag{2.224}$$

where,

$$L_1' \triangleq g_1\,g_4 - \frac{w_{R,o}}{v_{fg}G_{R,o}} \tag{2.225}$$

$$L_2' \triangleq g_2\,g_4 \tag{2.226}$$

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$$L_3' \triangleq g_3\, g_4 - w_{R,o}\, Sp \qquad (2.227)$$

$$g_4 \triangleq \frac{w_{R,o}\, \langle \hat{j}_R \rangle_o}{v_{fg} G_{R,o}^2} + \left(1 - \langle \alpha_R \rangle_o^{OUT}\right) A_R \qquad (2.228)$$

Using Eqs. (2.180) and (2.183), Eq. (2.224) becomes,

$$\delta\hat{w}_{SW} = L_1\, \delta\langle\hat{j}\rangle_R^{IN} + L_2\, \delta\langle\hat{\alpha}\rangle_R^{IN} + L_3\, \delta\hat{p} \qquad (2.229)$$

where,

$$L_1 \triangleq L_1' \qquad (2.230)$$

$$L_2 \triangleq L_2'\, e^{-\frac{s\Delta z_R}{C_{K,R,o}}} \qquad (2.231)$$

$$L_3 \triangleq L_1'\, C_{1,R}\, \Delta z_R + L_2' \frac{C_{2,R}}{s} \left(1 - e^{-\frac{s\Delta z_R}{C_{K,R,o}}}\right) + L_3' \qquad (2.232)$$

Substituting Eqs. (H-38) and (H-39) into Eq. (2.229), we obtain,

$$\delta\hat{w}_{SW} = L_1^*\, \delta\langle\hat{j}\rangle_p^{IN} + L_2^*\, \delta\langle\hat{\alpha}\rangle_p^{IN} + L_3^*\, \delta\hat{p} \qquad (2.233)$$

where,

$$L_1^* \triangleq L_1\, J_{1,R}^* + L_2\, K_{1,R}^* \qquad (2.234)$$

$$L_2^* \triangleq L_1\, J_{2,R}^* + L_2\, K_{2,R}^* \qquad (2.235)$$

$$L_3^* \triangleq L_1\, J_{3,R}^* + L_2\, K_{3,R}^* + L_3 \qquad (2.236)$$

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Finally, using Eqs. (G-41) and (G-47), we have,

$$\delta\hat{w}_{SW} = \sum_{j=1}^{N} W_{1,j}\,\delta\hat{j}_{in,j} + \sum_{j=1}^{N} W_{2,j}^{1\phi} \sum_{\ell}^{L_j} H'_{\ell,j}\,\delta\hat{q}'''_{\ell,j} + \sum_{j=1}^{N} \sum_{i=D}^{K_j} W_{2,j}^{i}\,\delta\hat{q}'''_{i,j}$$

$$+ W_3\,\delta\hat{h}_{in} + W_4\,\delta\hat{p} \tag{2.237}$$

where,

$$W_{1,j} \triangleq L_1^{*} B_{1,j}^{*} + L_2^{*} K_{1,j}^{*} \tag{2.238}$$

$$W_{2,j}^{1\phi} \triangleq L_1^{*} B_{2,j}^{*1\phi} + L_2^{*} K_{2,j}^{*1\phi} \tag{2.239}$$

$$W_{2,j}^{i} \triangleq L_1^{*} B_{2,j}^{*i} + L_2^{*} K_{2,j}^{*i} \tag{2.240}$$

$$W_3 \triangleq L_1^{*} B_3^{*} + L_2^{*} K_3^{*} \tag{2.241}$$

$$W_4 \triangleq L_1^{*} B_4^{*} + L_2^{*} K_4^{*} + L_3^{*} \tag{2.242}$$

Evaluating the terms $\delta\hat{w}_R$, and $\delta\hat{\langle\bar{\rho}_R\rangle}$ in the same way as done for $\delta\hat{w}_{SW}$, yields,

$$\delta\hat{w}_{R} = \sum_{j=1}^{N} X_{1,j}\,\delta\hat{j}_{in,j} + \sum_{j=1}^{N} X_{2,j}^{1\phi} \sum_{\ell}^{L_j} H'_{\ell,j}\,\delta\hat{q}'''_{\ell,j} + \sum_{j=1}^{N} \sum_{i=D}^{K_j} X_{2,j}^{i}\,\delta\hat{q}'''_{i,j}$$

$$+ X_3\,\delta\hat{h}_{in} + X_4\,\delta\hat{p} \tag{2.243}$$

and,

$$\delta\hat{\langle\bar{\rho}_R\rangle} = \sum_{j=1}^{N} \Upsilon_{1,j}\,\delta\hat{j}_{in,j} + \sum_{j=1}^{N} \Upsilon_{2,j}^{1\phi} \sum_{\ell}^{L_j} H'_{\ell,j}\,\delta\hat{q}'''_{\ell,j} + \sum_{j=1}^{N} \sum_{i=D}^{K_j} \Upsilon_{2,j}^{i}\,\delta\hat{q}'''_{i,j}$$

$$+ \Upsilon_3\,\delta\hat{h}_{in} + \Upsilon_4\,\delta\hat{p} \tag{2.244}$$

where,

$$X_{1,j} \triangleq M_1^* B_{1,j}^* + M_2^* K_{1,j}^* \tag{2.245}$$

$$X_{2,j}^{1\phi} \triangleq M_1^* B_{2,j}^{*1\phi} + M_2^* K_{2,j}^{*1\phi} \tag{2.246}$$

$$X_{2,j}^{i} \triangleq M_1^* B_{2,j}^{*i} + M_2^* K_{2,j}^{*i} \tag{2.247}$$

$$X_3 \triangleq M_1^* B_3^* + M_2^* K_3^* \tag{2.248}$$

$$W_4 \triangleq L_1^* B_4^* + L_2^* K_4^* + L_3^* \tag{2.249}$$

$$M_1^* \triangleq M_1 J_{1,R}^* + M_2 K_{1,R}^* \tag{2.250}$$

$$M_2^* \triangleq M_1 J_{2,R}^* + M_2 K_{2,R}^* \tag{2.251}$$

$$M_3^* \triangleq M_1 J_{3,R}^* + M_2 K_{3,R}^* + M_3 \tag{2.252}$$

$$M_1 \triangleq M_1' \tag{2.253}$$

$$M_2 \triangleq M_2' e^{-\frac{s\Delta z_R}{C_{K,R,o}}} \tag{2.254}$$

$$M_3 \triangleq M_1' C_{1,R} \Delta z_R + M_2' \frac{C_{2,R}}{s} \left(1 - e^{-\frac{s\Delta z_R}{C_{K,R,o}}}\right) + M_3' \tag{2.255}$$

$$M_1' \triangleq A_R g_1 \tag{2.256}$$

$$M_2' \triangleq A_R g_2 \tag{2.257}$$

$$M_3' \triangleq A_R\, g_3 \tag{2.258}$$

By using the following replacement,

$$M_1' \triangleq 0 \tag{2.259}$$

$$M_1' \triangleq -\Delta\rho \tag{2.260}$$

$$M_1' \triangleq \langle \alpha_R \rangle \frac{d\rho_g}{dp} \tag{2.261}$$

and Eqs. (2.245)-(2.255), the coefficients $\gamma_{1,j}$, $\gamma_{2,j}^{1\phi}$, etc. for $\delta\langle\hat{\bar{\rho}}_R\rangle$ can also be obtained as that of $X_{1,j}$, $X_{2,j}^{1\phi}$, etc.

2.7 Steam Separator

The modeling for steam separators is obtained from Ref. (5), which is based on the following assumptions:

1. The behavior of the steam separators is adequately described by the response of one lumped average separator.
2. The steam separators near the inlet of the separator giving a central core of vapor and a layer of liquid spiraling up the separator wall.
3. The principle inertial effects are due to the layer of liquid. (All other ℓ/A terms are small compared to this value.)

A force balance on the liquid flow spiraling along the wall gives,

$$\frac{1}{g_c}\frac{\bar{\ell}}{\bar{A}}\frac{dw_{SW}}{dt} = \Delta p_{SS} - \frac{g}{g_c}\langle\bar{\rho}_R\rangle\ell_{sep} - K_{sep}\frac{w_R^2}{2g_c\langle\bar{\rho}_R\rangle A_{SS}^2} \tag{2.262}$$

where separator geometry is given in Fig. 4.

Steady-State

$$\Delta p_{SS,0} = \frac{g}{g_c}\langle\bar{\rho}_R\rangle\ell_{sep} - K_{sep}\frac{w_R^2}{2g_c\langle\bar{\rho}_R\rangle A_{SS}^2} \tag{2.263}$$

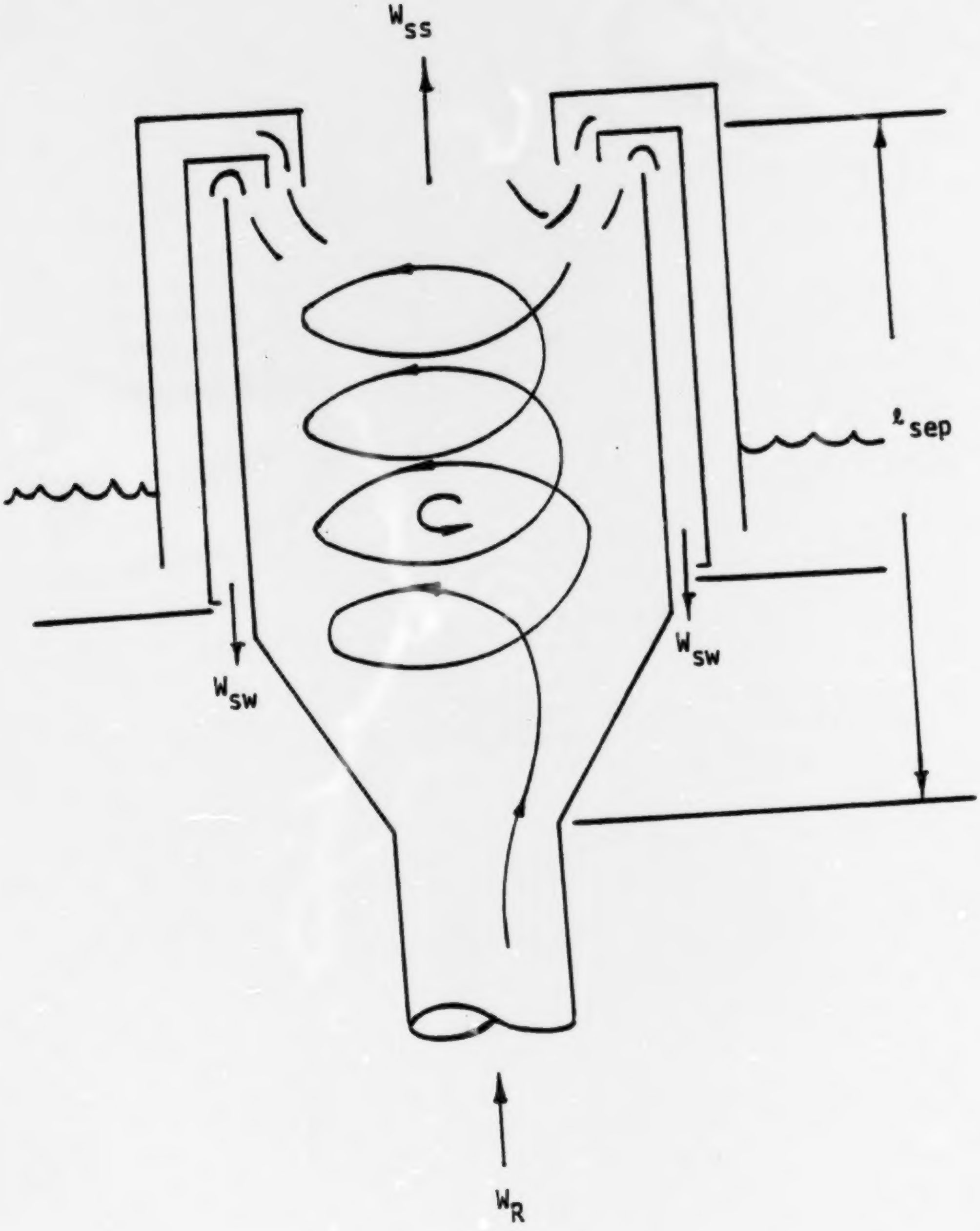
W_{ss}
ℓ_{sep}
W_{sw}
W_{sw}
W_R

Figure 4 Steam Separator Schematic

Transient State

Perturbing and Laplace transforming Eq. (2.262) yields,

$$\delta\Delta\hat{p}_{SS} = \frac{\tilde{\ell}}{g_c\ \tilde{A}}\, s\delta\hat{w}_{SW} + \frac{K_{sep}\ w_{R,o}}{g_c\ \langle\bar{\rho}_R\rangle_o\ A_{SS}^2}\,\delta\hat{w}_R + \left(\frac{g}{g_c}\ \ell_{sep} - \frac{K_{sep}\ w_{R,o}^2}{2g_c\ A_{SS}^2\ \langle\bar{\rho}_R\rangle_o^2}\right)\delta\langle\hat{\rho}\rangle_R \qquad (2.264)$$

Substituting Eqs. (2.237), (2.243), and (2.244) into Eq. (2.264) yields,

$$\delta(\Delta\hat{p})_{SS} = \sum_{j=1}^{N} S_{J,j}\ \delta\hat{j}_{in,j} + \sum_{j=1}^{N} S_{q,j}^{1\phi} \sum_{\ell}^{L_j} H'_{\ell,j}\ \delta\hat{q}'''_{\ell,j} + \sum_{j=1}^{N}\sum_{i=D}^{K_j} S_{2,j}^{i}\ \delta\hat{q}'''_{i,j}$$

$$+ S_h\ \delta\hat{h}_{in} + S_p\ \delta\hat{p} \qquad (2.265)$$

where,

$$S_{J,j} \triangleq aW_{1,j} + bX_{1,j} + cY_{1,j} \qquad (2.266)$$

$$S_{J,j}^{1\phi} \triangleq aW_{2,j}^{1\phi} + bX_{2,j}^{1\phi} + cY_{2,j}^{1\phi} \qquad (2.267)$$

$$S_{q,j}^{i} \triangleq aW_{2,j}^{i} + bX_{2,j}^{i} + cY_{2,j}^{i} \qquad (2.268)$$

$$S_h \triangleq aW_3 + bX_3 + cY_3 \qquad (2.269)$$

$$S_p \triangleq aW_4 + bX_4 + cY_4 \qquad (2.270)$$

$$a \triangleq \frac{s\ \tilde{\ell}}{g_c\ \tilde{A}} \qquad (2.271)$$

$$b \triangleq \frac{K_{sep}\ w_{R,o}}{g_c\ \langle\bar{\rho}_R\rangle_o\ A_{SS}^2} \qquad (2.272)$$

$$c \triangleq \frac{g}{g_c}\,\ell_{sep} - \frac{K_{sep}\,w_{R,o}^2}{2g_c\,A_{SS}^2\,\langle\bar{\rho}_R\rangle_o^2} \qquad (2.273)$$

2.8 Dynamics of the Recirculation Loop

The single-phase portion of the external recirculation loop was divided into three control volumes. Control volume-1 is occupied by saturated water. Control volume-2 is occupied by subcooled water. As shown in Fig. 5, the boundary between these two control volumes is at the location of the feedwater sparger ring, where highly subcooled feedwater is injected. Control volume-3 is the lower plenum node.

Let us now consider a mixing control volume at the junction between control volumes 1 and 2. Assuming instantaneous and perfect mixing of the feedwater and saturated recirculation water yields,

$$w_e + w_{fw} - w_{mix} = 0 \qquad (2.274)$$

$$w_e\,h_f + w_{fw}\,h_{fw} - w_{mix}\,h_{mix} = 0 \qquad (2.275)$$

In the steady-state case, Eqs. (2.274) and (2.275) yield,

$$w_{mix,o} = w_{e,o} + w_{fw,o} \qquad (2.276)$$

$$h_{mix,o} = \frac{w_{e,o}\,h_f + w_{fw,o}\,h_{fw}}{w_{mix,o}} \qquad (2.277)$$

In the transient case, we can perturb and Laplace transform Eqs. (2.274) and (2.275) to obtain,

$$\delta\hat{w}_{mix} = \delta\hat{w}_e + \delta\hat{w}_{fw} \qquad (2.278)$$

and,

$$\delta\hat{w}_e\,h_f + w_{e,o}\frac{dh_f}{dp}\,\delta\hat{p} + \delta\hat{w}_{fw}\,h_{fw} + w_{fw,o}\,\delta\hat{h}_{fw} - \delta\hat{w}_{mix}\,h_{mix,o}$$

$$- w_{mix,o}\,\delta\hat{h}_{mix} = 0 \qquad (2.279)$$

Since the feedwater flow rate and enthalpy are externally controlled by a system having a large time constant, we set,

$$\delta\hat{w}_{fw} = 0 \qquad (2.280)$$

and,

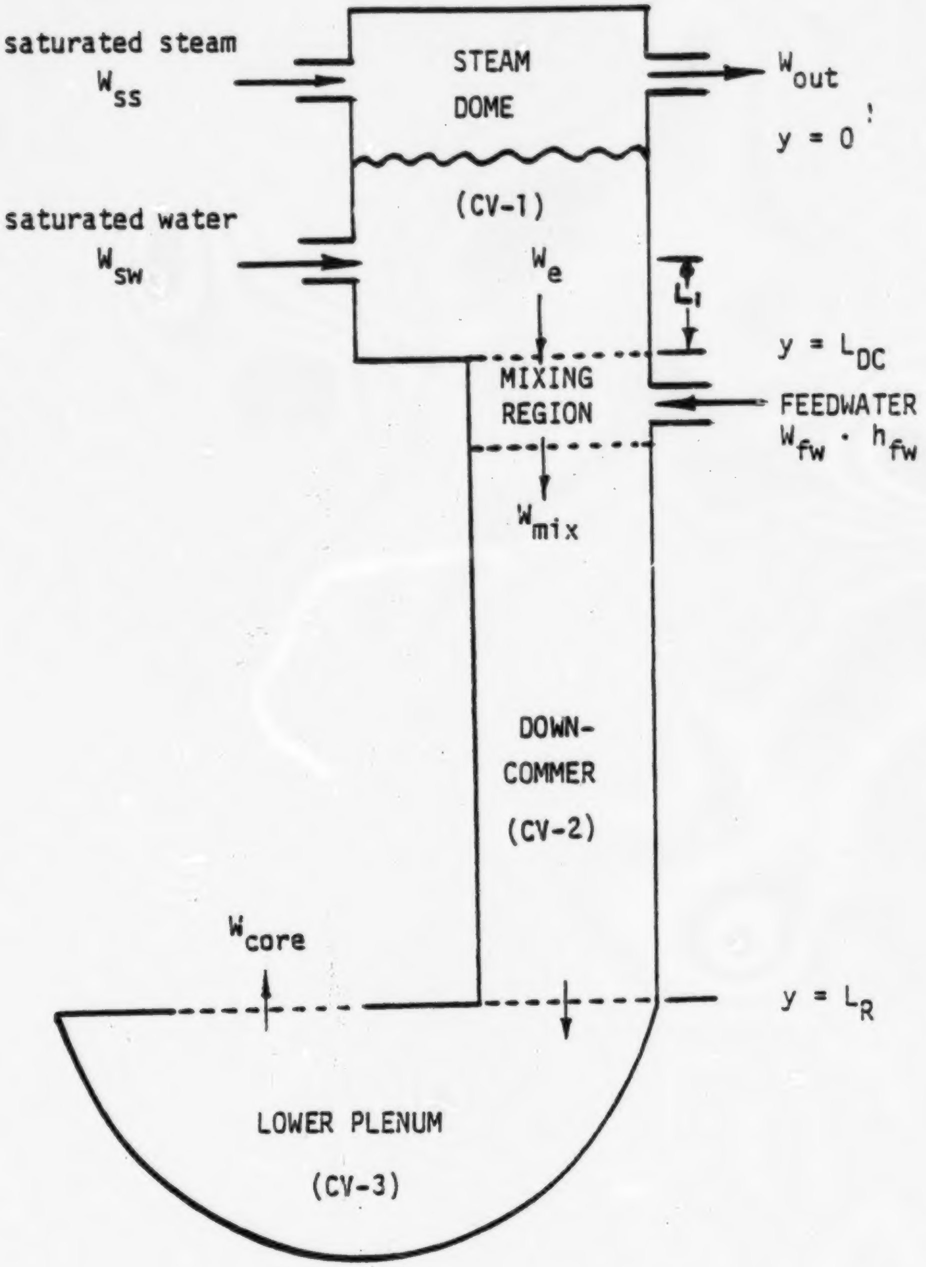
saturated steam
W_{ss}
STEAM
DOME
W_{out}
$y = 0$
(CV-1)
saturated water
W_{sw}
W_e
L_1
$y = L_{DC}$
MIXING
REGION
FEEDWATER
$W_{fw} \cdot h_{fw}$
W_{mix}
DOWN-
COMMER
(CV-2)
W_{core}
$y = L_R$
LOWER PLENUM
(CV-3)

Figure 5 Control Volumes in the Recirculation Loop

Consequently, Eqs. (2.278) and (2.279), respectively, reduce to,

$$\delta\hat{w}_{mix} = \delta\hat{w}_e \tag{2.282}$$

$$\delta\hat{h}_{mix} = \frac{w_{fw,o}}{w^2_{mix,o}} \left(h_f - h_{fw}\right) \delta\hat{w}_e + \frac{w_{e,o}}{w_{mix,o}} \frac{dh_f}{dp} \delta\hat{p} \tag{2.283}$$

Let us now consider control volume-2. The one-dimensional mass and energy conservation equations for the subcooled water in this control volume are,

Continuity Equation

$$\frac{\partial}{\partial y} j_{DC} = 0 \tag{2.284}$$

Energy Equation

$$\rho_\ell \left(\frac{\partial h_{DC}}{\partial t} + j_{DC} \frac{\partial h_{DC}}{\partial y}\right) = \frac{1}{J} \frac{dp}{dt} - \frac{q_v'' P_{H,V}}{A_{DC}} \tag{2.285}$$

The boundary conditions for Eqs. (2.284) and (2.285) are,

$$j_{DC} \Big|_{y=L_{DC}} = \frac{w_{mix}}{\rho_\ell A_{DC}} \tag{2.286}$$

$$h_{DC} \Big|_{y=L_{DC}} = h_{mix} \tag{2.287}$$

Assuming a constant cross sectional area for control vomume-2, Eq. (2.284) yields,

$$j_{DC} = \frac{w_{mix}}{\rho_\ell A_{DC}} \tag{2.288}$$

Hence, we have

$$\delta\hat{j}_{DC} = \frac{1}{\rho_\ell A_{DC}} \delta\hat{w}_{mix} \tag{2.289}$$

and,

$$j_{DC,o} = \frac{w_{mix,o}}{\rho_\ell A_{DC}} \tag{2.290}$$

At steady-state, Eq. (2.285) reduces to,

$$\frac{dh_{DC,o}}{dy} = - \frac{q''_v P_{H,v}}{\rho_\ell J_{DC} A_{DC}} \tag{2.291}$$

Thus,

$$h_{DC,o} = h_{mix,o} - \frac{q''_{v,o} P_{H,v}}{\rho_\ell J_{DC,o} A_{DC}} (y - L_{DC}) \tag{2.292}$$

Perturbing and Laplace transforming Eqs. (2.285) and (2.287), gives,

$$\frac{\partial \delta \hat{h}_{DC}}{\partial y} + \frac{s}{J_{DC,o}} \delta \hat{h}_{DC} = \frac{s}{J \rho_\ell J_{DC}} \delta \hat{p} - \frac{q''_{v,o} P_{H,v}}{w_{mix,o}} \left(\frac{\delta \hat{q}''_v}{q''_{v,o}} - \frac{\delta \hat{w}_{mix}}{w_{mix,o}} \right) \tag{2.293}$$

$$\delta \hat{h}_{DC} \Big|_{y=L_{DC}} = \delta \hat{h}_{mix} \tag{2.294}$$

The vessel wall heat flux perturbation, $\delta \hat{q}''_v$, can be obtained by solving the heat conduction equation for vessel wall. The details are shown in Appendix-K of reference 1. After substituting $\delta \hat{q}''_v$ [Eq. (K-4) in reference 1] into Eq. (2.293) and using (2.294), the $\delta \hat{h}_{DC}$ can be solved as,

$$\delta \hat{h}_{DC} = \delta \hat{h}_{mix}\, e^{-\phi(y-L_{DC})} + \frac{s}{J \phi \rho_\ell J_{DC}} \left[1 - e^{-\phi(y-L_{DC})}\right] \delta \hat{p} + \frac{\theta}{\phi - b_1} \left[e^{-b_1(y-L_{DC})} - e^{-\phi(y-L_{DC})}\right] \frac{\delta \hat{w}_{mix}}{w_{mix,o}} \tag{2.295}$$

where, as given in Appendix XI of reference 1,

$$\theta(s) \triangleq - \frac{b P_{H,v}}{w_o} [a \chi(s) - 1] \tag{2.296}$$

$$\phi(s) \triangleq \frac{\rho A}{w_o} s + \frac{P_{H,v} H_{1\phi,o} \chi(s)}{w_o C_{pf}} \tag{2.297}$$

$$\chi(s) \triangleq \frac{k_v \varepsilon_v}{k_v \varepsilon_v + H_{1\phi,o} \tanh(\varepsilon_v d_1)} \tag{2.298}$$

$$b_1 \triangleq \frac{P_{H,v} H_{1\phi,o}}{W_o C_{pf} \left(1 + \frac{d_1 H_{1\phi,o}}{k_v}\right)} \tag{2.299}$$

$$b \triangleq \frac{H_{1\phi,o}}{1 + \frac{d_1 H_{1\phi,o}}{k_v}} \left(T_{bulk}^{in} - T_o\right) \tag{2.300}$$

Let us now consider the lower plenum, control volume-3. The convervation of energy on control volume-3 is given by,

$$\frac{d}{dt} \left[M_{Lp} \left(h - \frac{p}{J\rho_\ell}\right)\right] = w_{mix}\, h_{LP}^{IN} - w_{core}\, h - q''_{LP} A_{H,LP} \tag{2.301}$$

Note that because of the incompressibility assumption, conservation of mass in control volume-3 gives,

$$w_{mix} = w_{core} \tag{2.302}$$

Hence, we have,

$$w_{mix,o} = w_{core,o} \tag{2.303}$$

and,

$$\delta\hat{w}_{mix} = \delta\hat{w}_{core} \tag{2.304}$$

After perturbing and Laplace transforming Eq. (2.301), we obtain,

$$\delta\hat{h} = \frac{1}{M_{Lp,o} s + w_{core}} \left(w_{core,o} \delta\hat{h}^{IN}_{Lp} + \frac{M_{Lp,o} s}{J\rho_\ell} \delta\hat{p} - \delta\hat{q}''_{Lp} A_{H,LP}\right) \tag{2.305}$$

where,

$$\delta\hat{h}^{IN}_{Lp} = \delta\hat{h}_{DC} \Big|_{y=L_R} \tag{2.306}$$

Note that the term $\delta\hat{q}''_{Lp}$ is derived in reference 1 as,

$$\delta\hat{q}''_{Lp} = x(s) \left[\frac{aq''_{Lp,o}}{W_o} \delta\hat{w}_{core} + \frac{H_{1\phi,o}}{C_{pf}} \delta\hat{h}\right] \tag{2.307}$$

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Combining Eq. (2.283) with Eqs. (2.282) and (2.304) yields,

$$\delta\hat{h}_{mix} = \frac{w_{fw,o}}{w_{mix,o}^{2}} (h_f - h_{fw})\, \delta\hat{w}_{core} + \frac{w_{e,o}}{w_{mix,o}} \frac{dh_f}{dp}\, \delta\hat{p} \tag{2.308}$$

Consequently, From Eqs. (2.295), (2.306), and (2.308), we have,

$$\delta\hat{h}_{Lp}^{IN} = E_1\, \delta\hat{w}_{core} + E_2\, \delta\hat{p} \tag{2.309}$$

where,

$$E_1 \triangleq \frac{w_{fw,o}}{w_{mix,o}^{2}} (h_f - h_{fw})\, e^{-\phi\Delta L_R} + \frac{\theta}{(\phi - b_1)\, w_{mix,o}} \left(e^{-b_1\Delta L_R} - e^{-\phi\Delta L_R}\right) \tag{2.310}$$

$$E_2 \triangleq \frac{s}{J\rho_\ell \phi j_{DC}} \left(1 - e^{-\phi\Delta L_R}\right) + \frac{w_{e,o}}{w_{mix,o}} \frac{dh_f}{dp}\, e^{-\phi\Delta L_R} \tag{2.311}$$

$$\Delta L_R \triangleq L_R - L_{Dc} \tag{2.312}$$

Substituting Eq. (2.309) into Eq. (2.305), we obtain,

$$\delta\hat{h} = H_1\, \delta\hat{w}_{core} + H_2\, \delta\hat{p} \tag{2.313}$$

where,

$$H_1 = \left[\frac{w_{core,o} E_1 - \dfrac{\chi(s)\, A_{H,Lp}\, a q''_{Lp,o}}{w_{core,o}}}{M_{Lp,o} s + w_{core,o} + \dfrac{\chi(s) H_{1\phi,o} A_{H,Lp}}{C_{pf}}} \right] \tag{2.314}$$

$$H_2 = \left[\frac{M_{Lp,o} s / J\rho_\ell + w_{core,o} E_2}{M_{Lp,o} s + w_{core,o} + \dfrac{\chi(s) H_{1\phi,o} A_{H,Lp}}{C_{pf}}} \right] \tag{2.315}$$

Since it is assumed that the inlet enthalpy perturbation of each channel in the core is equal to $\delta\hat{h}$,

$$\delta\hat{h}_{in} = \delta\hat{h} \tag{2.316}$$

Thus, by Eq. (2.313) we have,

$$\delta\hat{h}_{in} = H_1\,\delta\hat{w}_{core} + H_2\,\delta\hat{p} \tag{2.317}$$

The total pressure drop across the external (liquid-phase) portion of the recirculation loop is given by,

$$\Delta p_L = -\int \frac{\partial p}{\partial z}\,dz + \text{Local Loss} - \text{Jet Pump Head Gain} \tag{2.318}$$

where, the momentum equation for single-phase liquid in the external portion of the loop is

$$-\frac{\partial p}{\partial z} = \frac{\rho_\ell}{g_c}\frac{dj}{dt} + \frac{f\rho_\ell j^2}{2g_c D_H} - \frac{g}{g_c}\rho_\ell \tag{2.319}$$

The steady-state pressure drop can be obtained from Eqs. (2.318) and (2.319) as,

$$\Delta p_{L,o} = \sum_m \left[\frac{f_m\rho_\ell j_m^2}{2g_c D_{H,m}}\Delta L_{f,m} + \frac{g}{g_c}\rho_\ell\,\Delta L_{g,m} + \frac{1}{2g_c}K_m\rho_\ell j_m^2\right] - \Delta p_J \tag{2.320}$$

where,

m = control volume index,

$\Delta L_{f,m}$, $\Delta L_{g,m}$ = length of flow path and gravity elevation for m^{th} control volume, respectively,

K_m = local loss coefficient for the m^{th} control volume,

Δp_J = Jet pump head gain.

Perturbing and Laplace transforming Eqs. (2.318) and (2.319) yields,

$$\delta\Delta\hat{p}_L = \sum_m \left[\frac{\rho_\ell}{g_c}\,s\,\delta\hat{j}_m\,\Delta L_{f,m} + \left(\frac{f\rho_\ell j_m}{g_c D_{H,m}}\Delta L_{f,m} + \frac{K_m}{g_c}\rho_\ell j_m\right)\delta\hat{j}_m\right] - \delta\Delta\hat{p}_J \tag{2.321}$$

Taking into account that the flow velocity in the m^th control volume is,

$$j_m = \frac{w_{core}}{\rho_\ell A_m} \tag{2.322}$$

we have,

$$\delta\hat{j}_m = \frac{1}{\rho_\ell A_m}\,\delta\hat{w}_{core} \tag{2.323}$$

Since,

$$\delta\Delta\hat{p}_J = \xi\ \delta\hat{w}_{core} \tag{2.324}$$

where ξ is the slope of the jet-pump head-flow characteristic, Eq. (2.321) becomes,

$$\delta\Delta\hat{p}_L = R_5\delta\hat{w}_{core} \tag{2.325}$$

where,

$$R_5 \triangleq \frac{s}{g_c}\,L_s + \frac{w_{core,o}}{\rho_\ell g_c}\,L_f - \xi \tag{2.326}$$

$$L_s \triangleq \sum_m \frac{\Delta L_{f,m}}{A_m} \tag{2.327}$$

$$L_f \triangleq \sum_m \frac{1}{A_m^2}\left(\frac{f\Delta L_{f,m}}{D_{H,m}} + K_m\right) \tag{2.328}$$

CHAPTER 3

SYSTEM TRANSFER FUNCTIONS

In this chapter, the system pressure-to-power density (neutron flux) transfer function is drived. This transfer function is used if the pressure perturbation is the external forcing function in the analysis of BWR stability. Other system transfer functions due to various perturbations, such as power density, reactivity, inlet velocity, are discussed in reference 1.

3.1 Partial Transfer Functions

We first derive the power and system pressure-to-nodal void fraction transfer functions for coupled paralle channels. From Eq. (B-59) and Eqs. (B-145), (B-151) and (B-152), the perturbation in the nodal void fraction for the j^{th} channel is given as,

$$\delta\widehat{\langle\bar{\alpha}\rangle}_{k,j} = T_{1,k,j}\ \delta\hat{j}_{in,j} + \sum_{i=1}^{k-1} T^{i}_{2,k,j}\ \delta\hat{q}'''_{i,j} + T_{3,k,j}\ \delta\hat{h}_{in} + T_{4,k,j}\ \delta\hat{p} \tag{3.1}$$

where,

$$T_{1,k,j} \triangleq \psi_{1,k,j}\ B_{1,k,j} + \psi_{2,k,j}\ M_{1,k,j} + \psi_{3,k,j}\ K_{1,k,j} \tag{3.2}$$

$$T^{i}_{2,k,j} \triangleq \begin{cases} H'_{i,j}\left(\psi_{1,k,j}\ B^{1\phi}_{2,k,j} + \psi_{2,k,j}\ M^{1\phi}_{2,k,j} + \psi_{3,k,j}\ K^{1\phi}_{2,k,j}\right), & \text{if } i < D_j \\ \\ \psi_{1,k,j}\ B^{i}_{2,k,j} + \psi_{2,k,j}\ M^{i}_{2,k,j} + \psi_{3,k,j}\ K^{i}_{2,k,j}, & \text{if } i > D_j \end{cases} \tag{3.3}$$

$$T_{3,k,j} \triangleq \psi_{1,k,j}\ B_{3,k,j} + \psi_{2,k,j}\ M_{3,k,j} + \psi_{3,k,j}\ K_{3,k,j} \tag{3.4}$$

$$T_{4,k,j} \triangleq \psi_{1,k,j}\ B_{4,k,j} + \psi_{2,k,j}\ M_{4,k,j} + \psi_{3,k,j}\ K_{4,k,j} + \psi_{4,k,j} \tag{3.5}$$

With the aid of the pressure drop boundary conditions and inlet enthalpy dynamics, the perturbations of $\delta\hat{j}_{in,j}$ and $\delta\hat{h}_{in}$ in Eq. (3.1) can be expressed in terms of $\delta\hat{q}'''_{i,j}$ and $\delta\hat{p}$. In particular, the pressure drop boundary conditions given by Eqs. (2.91) and (2.92) yield,

$$\delta\Delta\hat{p}_j = \delta\Delta\hat{p}_i, \text{ for any two different channels } i \text{ and } j \tag{3.6}$$

and consequently,

$$\delta\Delta\hat{p}_i + \delta\Delta\hat{p}_{ext.\ loop} = 0 \text{ for all channels-}i \tag{3.7}$$

Using the inlet enthalpy dynamics given by Eq. (2.317) and substituting it into Eq. (2.94), the i^th channel pressure drop perturbation, $\delta\Delta\hat{p}_i$, can be expressed as,

$$\delta\Delta\hat{p}_i = P_{1,i}\ \delta\hat{j}_{in,i} + \sum_{k=1}^{K} P^{k}_{2,i}\ \delta\hat{q}'''_{k,i} + P^{*}_{3,i}\ \delta\hat{w}_{core} + P^{*}_{4,i}\ \delta\hat{p} \tag{3.8}$$

where,

$$P^{*}_{3,i} \triangleq P_{3,i}\ H_1 \tag{3.9}$$

$$P^{*}_{4,i} \triangleq P_{4,i} + P_{3,i}\ H_2 \tag{3.10}$$

The pressure drop perturbation across the external portion of the loop, $\delta\Delta p_{ext.\ loop}$ can obtained by adding Eqs. (2.161), (2.201), (2.265), and (2.325)

$$\delta\Delta\hat{p}_{ext.\ loop} = \delta\Delta\hat{p}_{UP} + \delta\Delta\hat{p}_{R} + \delta\Delta\hat{p}_{SS} + \delta\Delta\hat{p}_{L} = \sum_{j=1}^{N} Q_{1,j}\ \delta\hat{j}_{in,j}$$

$$+ \sum_{j=1}^{N} \sum_{i=1}^{K_j} Q^{i}_{2,j}\ \delta\hat{q}'''_{i,j} + Q_3\ \delta\hat{h}_{in} + Q_4\ \delta\hat{p} + Q_5\ \delta\hat{w}_{core} \tag{3.11}$$

where,

$$Q_{1,j} \triangleq UP_{J,j} + R_{J,j} + S_{J,j} \tag{3.12}$$

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$$Q^i_{2,j} \triangleq \begin{cases} UP^{1\phi}_{q,j}\ H'_{i,j} + R^{1\phi}_{q,j}\ H'_{i,j} + S^{1\phi}_{q,j}\ H'_{i,j} & , \text{ if } i < D_j \\ UP^{i}_{q,j} + R^{i}_{q,j} + S^{i}_{q,j} & , \text{ if } i > D_j \end{cases} \tag{3.13}$$

$$Q_3 \triangleq UP_h + R_h + S_h \tag{3.14}$$

$$Q_4 \triangleq UP_p + R_p + S_p \tag{3.15}$$

$$Q_5 \triangleq R_5 \tag{3.16}$$

Substituting Eq. (3.8) into Eq. (3.6), we obtain,

$$\begin{aligned} \delta\hat{j}_{in,j} = {} & \frac{P_{1,i}}{P_{1,j}}\ \delta\hat{j}_{in,i} + \frac{1}{P_{1,j}} \sum_{\ell=1}^{K_i} P^{\ell}_{2,i}\ \delta\hat{q}'''_{\ell,i} - \frac{1}{P_{1,j}} \sum_{\ell=1}^{K_j} P^{\ell}_{2,j}\ \delta\hat{q}'''_{\ell,j} \\ & + \frac{1}{P_{1,j}} \left(P^*_{3,i} - P^*_{3,j}\right) \delta\hat{w}_{core} + \frac{1}{P_{1,j}} \left(P^*_{4,i} - P^*_{4,j}\right) \delta\hat{p} \end{aligned} \tag{3.17}$$

Substituting Eqs. (3.8) and (3.11) into Eq. (3.7), and using Eq. (2.317) yields,

$$\begin{aligned} & \left(P_{1,i} + Q_{1,i}\right) \delta\hat{j}_{in,i} + \sum_{\substack{j=1 \\ j\neq i}}^{N} Q_{1,j}\ \delta\hat{j}_{in,j} + \sum_{\ell=1}^{K_i} P^{\ell}_{2,i}\ \delta\hat{q}'''_{\ell,i} + \sum_{j=1}^{N} \sum_{\ell=1}^{K_j} Q^{\ell}_{2,j}\ \delta\hat{q}'''_{\ell,j} \\ & + Q^*_{3,i}\ \delta\hat{w}_{core} + Q^*_{4,i}\ \delta\hat{p} = 0 \end{aligned} \tag{3.18}$$

where,

$$Q^*_{3,i} \triangleq \left(P_{3,i} + Q_3\right) H_1 \tag{3.19}$$

$$Q^*_{4,i} \triangleq P_{4,i} + Q_4 + \left(P_{3,i} + Q_3\right) H_2 \tag{3.20}$$

Substituting Eq. (3.17) into Eq. (3.18) yields,

$$\delta\hat{j}_{in,i} = V_{1,i} \left\{ \sum_{j=1}^{N} \frac{Q_{1,j}}{P_{1,j}} \left[\sum_{\ell=1}^{K_i} P^{\ell}_{2,i}\, \delta\hat{q}'''_{\ell,i} - \sum_{\ell=1}^{K_j} P^{\ell}_{2,j}\, \delta\hat{q}'''_{\ell,j} \right] + \sum_{\ell=1}^{K_i} P^{\ell}_{2,i}\, \delta\hat{q}'''_{\ell,i} \right.$$

$$\left. + \sum_{j=1}^{N} \sum_{\ell=1}^{K_j} Q^{\ell}_{2,j}\, \delta\hat{q}'''_{\ell,j} \right\} + V_{2,i}\, \delta\hat{p} + V_{3,i}\, \delta\hat{w}_{core} \qquad (3.21)$$

where,

$$V_{1,i} = -1 / \left(P_{1,i} + \sum_{j=1}^{N} Q_{1,j} \frac{P_{1,i}}{P_{1,j}}\right) \qquad (3.22)$$

$$V_{2,i} = V_{1,i} \left[Q^{*}_{4,i} + \sum_{\substack{j=1 \\ j\neq i}}^{N} \frac{(P^{*}_{4,i} - P^{*}_{4,j})}{P_{1,j}} Q_{1,j}\right] \qquad (3.23)$$

$$V_{3,i} = V_{1,i} \left[Q^{*}_{3,i} + \sum_{\substack{j=1 \\ j\neq i}}^{N} \frac{(P^{*}_{3,i} - P^{*}_{3,j})}{P_{1,j}} Q_{1,j}\right] \qquad (3.24)$$

Perturbing and Laplace transforming the flow condition, Eq. (2.93) yields,

$$\delta\hat{w}_{core} = \sum_{i=1}^{N} \rho_{\ell}\, A_{xs,i}\, \delta\hat{j}_{in,i} \qquad (3.25,$$

Substituting Eq. (3.21) into Eq. (3.25), we obtain,

$$\delta\hat{w}_{core} = \sum_{i=1}^{N} W_{1,i} \left\{ \sum_{j=1}^{N} \frac{Q_{1,j}}{P_{1,j}} \left[\sum_{\ell=1}^{K_i} P^{\ell}_{2,i}\, \delta\hat{q}'''_{\ell,i} - \sum_{\ell=1}^{K_j} P^{\ell}_{2,j}\, \delta\hat{q}'''_{\ell,j} \right] \right.$$

$$\left. + \sum_{j=1}^{N} \sum_{\ell=1}^{K_j} Q^{\ell}_{2,j}\, \delta\hat{q}'''_{\ell,j} + \sum_{\ell=1}^{K_i} P^{\ell}_{2,i}\, \delta\hat{q}'''_{\ell,i} \right\} + W_2\, \delta\hat{p} \qquad (3.26)$$

where,

$$W_{1,i} \triangleq \frac{\rho_\ell A_{xs,i} V_{1,i}}{1 - \sum_{n=1}^{N} \rho_\ell A_{xs,n} V_{3,n}} \tag{3.27}$$

$$W_2 \triangleq \frac{\sum_{i=1}^{N} \rho_\ell A_{xs,i} V_{2,i}}{1 - \sum_{n=1}^{N} \rho_\ell A_{xs,n} V_{3,n}} \tag{3.28}$$

Hence, Eq. (3.26) can be substituted into Eq. (3.21) to yield,

$$\begin{aligned} \delta\hat{j}_{in,i} = \sum_{j=1}^{N} \sum_{\ell=1}^{K_j} \{P^\ell_{2,j} [W^{*i}_{1,j} (1 + \sum_{m=1}^{N} \frac{Q_{1,m}}{P_{1,m}}) + V_{1,i}\, \delta_{ij} (\sum_{m=1}^{N} \frac{Q_{1,m}}{P_{1,m}})] \\ + [V_{1,i} + (\sum_{m=1}^{N} W^{*i}_{1,m}) (Q^\ell_{2,j} - \frac{Q_{1,j}}{P_{1,j}} P^\ell_{2,j})]\} \delta\hat{q}'''_{\ell,j} + W^*_{2,i}\, \delta\hat{p} \end{aligned} \tag{3.29}$$

where,

$$W^{*i}_{1,m} = V_{3,i} W_{1,m} \tag{3.30}$$

$$W^{*i}_{2,i} = V_{2,i} + V_{3,i} W_2 \tag{3.31}$$

Substituting Eq. (3.26) into Eq. (2.317), we obtain,

$$\begin{aligned} \delta\hat{n}_{in} = \sum_{j=1}^{N} \sum_{\ell=1}^{K_j} [(\sum_{m=1}^{N} \frac{Q_{1,m}}{P_{1,m}}) H^*_{1,j} P^\ell_{2,j} + (\sum_{m=1}^{N} H^*_{1,m}) (Q^\ell_{2,j} - \frac{Q_{1,j}}{P_{1,j}} P^\ell_{2,j})] \delta\hat{q}'''_{\ell,j} \\ + H^*_2\, \delta\hat{p} \end{aligned} \tag{3.32}$$

where,

$$H^*_{1,m} \triangleq H_1 W_{1,m} \tag{3.33}$$

$$H^*_2 \triangleq H_1 W_2 + H_2 \tag{3.34}$$

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Eqs. (3.29) and (3.32) can be rewritten in the matrix form as,

$$\delta\hat{j}_{in,i} = \underline{H}^t_{J,i}\ \delta\hat{\underline{q}}''' + W^*_{2,i}\ \delta\hat{p} \tag{3.35}$$

$$\delta\hat{h}_{in} = \underline{H}^t_h\ \delta\hat{\underline{q}}''' + H^*_2\ \delta\hat{p} \tag{3.36}$$

where,

$$\delta\hat{\underline{q}}''' \triangleq [\underbrace{\delta\hat{q}'''_{1,1}\ \delta\hat{q}'''_{2,1} \cdots \delta\hat{q}'''_{k_{1,1}}}_{1^{st}\text{ channel}}\ \underbrace{\delta\hat{q}'''_{1,2} \cdots \delta\hat{q}'''_{k_{2,2}}}_{2^{nd}\text{ channel}} \cdots \underbrace{\delta\hat{q}'''_{1,N} \cdots \delta\hat{q}_{k_{N,N}}}_{N^{th}\text{ channel}}]^t \tag{3.37}$$

$\underline{H}^t_{J,i}$ and $\underline{H}^t_h$ are the coefficient row vectors with respect to $\delta\hat{\underline{q}}'''$ for $\delta\hat{j}_{in,i}$ and $\delta\hat{h}_{in}$, respectively. The details are shown in the program listing.

Substituting Eqs. (3.35) and (3.36) into Eq. (3.1), we obtain,

$$\delta\langle\hat{\bar{\alpha}}\rangle_{k,j} = \underline{K}^t_{k,j}\ \delta\hat{\underline{q}}''' + K_{pk,j}\ \delta\hat{p} \tag{3.38}$$

where,

$$\underline{K}^t_{k,j} = T_{1,k,j}\ \underline{H}^t_{J,j} + \underline{T}^t_{2,k,j} + T_{3,k,j}\ \underline{H}^t_h \tag{3.39}$$

$$K_{pk,j} = T_{1,k,j}\ W^*_{2,j} + T_{3,k,j}\ H^*_2 + T_{4,k,j} \tag{3.40}$$

$$\underline{T}^t_{2,k,j} = [0 \ldots 0\ \underbrace{T^1_{2,k,j}\ T^2_{2,k,j} \cdots T^{k-1}_{2,k,j}\ 0\ 0 \ldots 0}_{j^{th}\text{ channel}}\ 0 \ldots 0] \tag{3.41}$$

Eq. (3.38) can be rewritten as,

$$\delta\langle\hat{\underline{\alpha}}\rangle = \underline{K}\ \delta\hat{\underline{q}}''' + \underline{K}_p\ \delta\hat{p} \tag{3.42}$$

where,

$$\delta\underline{\langle\hat{\alpha}\rangle} \triangleq [\underbrace{\delta\langle\hat{\bar{\alpha}}\rangle_{1,1}\ \delta\langle\hat{\bar{\alpha}}\rangle_{2,1}\ \cdots\ \delta\langle\hat{\bar{\alpha}}\rangle_{k_1,1}}_{1^{st}\ \text{channel}}\ \ \underbrace{\delta\langle\hat{\bar{\alpha}}\rangle_{1,2}\ \cdots\ \delta\langle\hat{\bar{\alpha}}\rangle_{k_2,2}}_{2^{nd}\ \text{channel}}\ \cdots$$

$$\underbrace{\delta\langle\hat{\bar{\alpha}}\rangle_{1,N}\ \cdots\ \delta\langle\hat{\bar{\alpha}}\rangle_{k_N,N}]^t}_{N^{th}\ \text{channel}} \tag{3.43}$$

$$\underline{K} \triangleq \begin{bmatrix} T_{1,1,1}\,\underline{H}^t_{J,1} + \underline{T}^t_{2,1,1} + T_{3,1,1}\,\underline{H}^t_h \\ \vdots \\ T_{1,k_1,1}\,\underline{H}^t_{J,1} + \underline{T}^t_{2,k_1,1} + T_{3,k_1,1}\,\underline{H}^t_h \\ T_{1,1,2}\,\underline{H}^t_{J,2} + \underline{T}^t_{2,1,2} + T_{3,1,2}\,\underline{H}^t_h \\ \vdots \\ T_{1,k_2,2}\,\underline{H}^t_{J,2} + \underline{T}^t_{2,k_2,2} + T_{3,k_2,2}\,\underline{H}^t_h \\ \vdots \\ T_{1,k_N,N}\,\underline{H}^t_{J,N} + \underline{T}^t_{2,k_N,N} + T_{3,k_N,N}\,\underline{H}^t_h \end{bmatrix} \tag{3.44}$$

$$\underline{K}_p = [\underbrace{K_{p1,1}\ K_{p2,1}\ \cdots\ K_{pk_1,1}}_{1^{st}\ \text{channel}}\ \underbrace{K_{p1,2}\ \cdots\ K_{pk_2,2}}_{2^{nd}\ \text{channel}}\ \cdots\ \underbrace{K_{p1,N}\ \cdots\ K_{pk_N,N}]^t}_{N^{th}\ \text{channel}} \tag{3.45}$$

Here, $\underline{K}$ is the power density-to-nodal void fraction transfer function matrix, and $\underline{K}_p$ is the system pressure-to-nodal void fraction transfer function matrix.

3.2 System Transfer Functions

By coupling Eq. (3.42) with the reactor kinetics equations, we obtain the system pressure-to-power density (neutron flux) transfer function. From reference 4, the reactor kinetics gives,

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$$\underline{P}\,\delta\underline{\hat{q}}''' = \underline{I}\,\delta\langle\underline{\hat{\alpha}}\rangle \tag{3.46}$$

Substituting Eq. (3.42) into (3.46), we obtain,

$$\delta\underline{\hat{q}}''' = \underline{Q}_p\,\delta\hat{p} \tag{3.47}$$

where the vector, $\underline{Q}_p$, defining the system pressure-to-power density (i.e., neutron flux) transfer function, is given by,

$$\underline{Q}_p = (\underline{P} - \underline{I}\,\underline{K})^{-1}\,\underline{I}\,\underline{K}_p \tag{3.48}$$

Some other useful system transfer functions can also be determined when the system pressure perturbation is the input excitation. In particular, substituting Eq. (3.47) into Eqs. (3.35) and (3.36), we obtain,

$$\delta\hat{j}_{in,i} = J_{p,i}\,\delta\hat{p} \tag{3.49}$$

$$\delta\hat{h}_{in} = H_p\,\delta\hat{p} \tag{3.50}$$

where,

$$J_{p,i} \triangleq \underline{H}^t_{J,i}\,\underline{Q}_p + W^*_{2,i} \tag{3.51}$$

$$H_p \triangleq \underline{H}^t\,\underline{Q}_p + H^*_2 \tag{3.52}$$

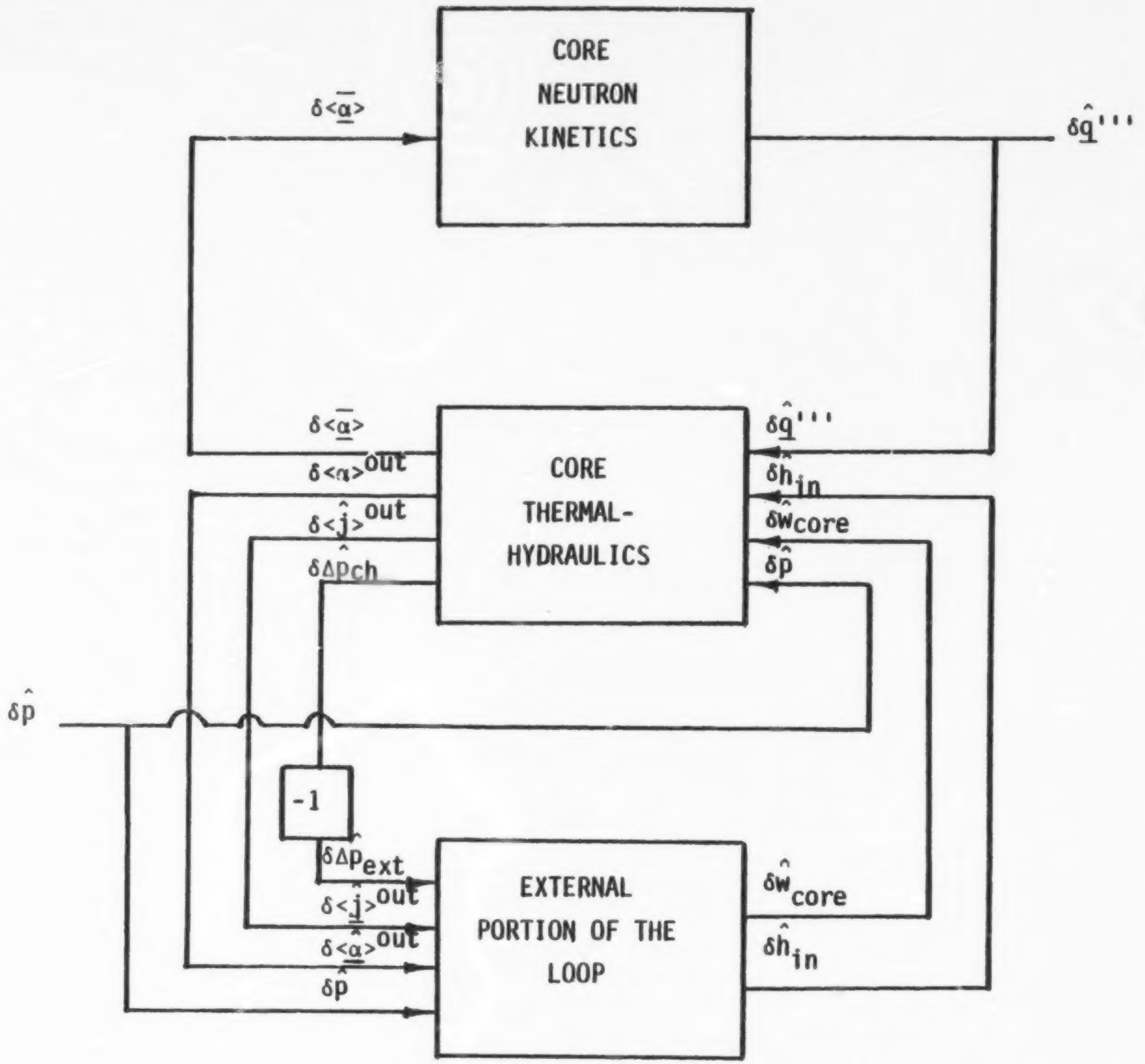
As can be seen, H_p determines the pressure-to-inlet enthalpy transfer function. The system pressure-to-core flow rate transfer function can be obtained from Eqs. (3.25) and (3.49) as,

$$\delta\hat{w}_{core} = H_{wp}\,\delta\hat{p} \tag{3.53}$$

where,

$$H_{wp} = \sum_{i=1}^{N} \rho_\ell\,A_{xs,i}\,J_{p,i} \tag{3.54}$$

The model discussed in this report developed for BWR stability analyses in which system pressure was the external perturbation is summarized in the block diagram shown in Fig 6.



CORE NEUTRON KINETICS
$\delta\langle\bar{\underline{\alpha}}\rangle$
$\delta\hat{\underline{q}}'''$
CORE THERMAL-HYDRAULICS
$\delta\langle\bar{\underline{\alpha}}\rangle$
$\delta\langle\alpha\rangle^{out}$
$\delta\langle\hat{j}\rangle^{out}$
$\delta\Delta\hat{p}_{ch}$
$\delta\hat{\underline{q}}'''$
$\delta\hat{h}_{in}$
$\delta\hat{w}_{core}$
$\delta\hat{p}$
$\delta\hat{p}$
-1
EXTERNAL PORTION OF THE LOOP
$\delta\Delta\hat{p}_{ext}$
$\delta\langle\hat{\underline{j}}\rangle^{out}$
$\delta\langle\hat{\underline{\alpha}}\rangle^{out}$
$\delta\hat{p}$
$\delta\hat{w}_{core}$
$\delta\hat{h}_{in}$

Figure 6 BWR Block Diagram for System Pressure Perturbation

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CHAPTER 4

COMPARISON WITH OUT-OF-CORE DATA

As mentioned before, the NUFREQ-NP code is a modified version of NUFREQ-N. Although the main advantage of NUFREQ-NP over NUFREQ-N is that the former can be used to investigate stability of BWR systems undergoing perturbations in the coolant pressure, some other improvements have also been made dealing with various solution algorithms. In order to compare the two codes, NUFREQ-NP was assessed against some of the same data used for NUFREQ-N assessment. The FRIGG Loop Test (7) results, which were run at constant system pressure, was considered to be the most reliable data set, and thus was used. The FRIGG Loop conditions and characteristics used in the computations are, in general, the same as those tabulated in reference 1. The only significant difference is that in the present case it was found that an inlet loss coefficient of 8.5 mathces the experimental data much better than the value 5.1 used in reference 1. Also, 8.5 is closer to that reported in the FRIGG Loop experiment. The power-to-flow transfer function was calculated by NUFREQ-NP for three FRIGG Loop tests. The results are shown in the Bode plots in Figs. 7 to 12, along with the measured transfer function. The NUFREQ-NP predictions of the transfer function are in good agreement with the measurements. By comparing these results with those shown in Figs. 5.13-5.18 of reference 1, it is seen that the NUFREQ-NP's prediction capabilities are even better than those of NUFREQ-N.

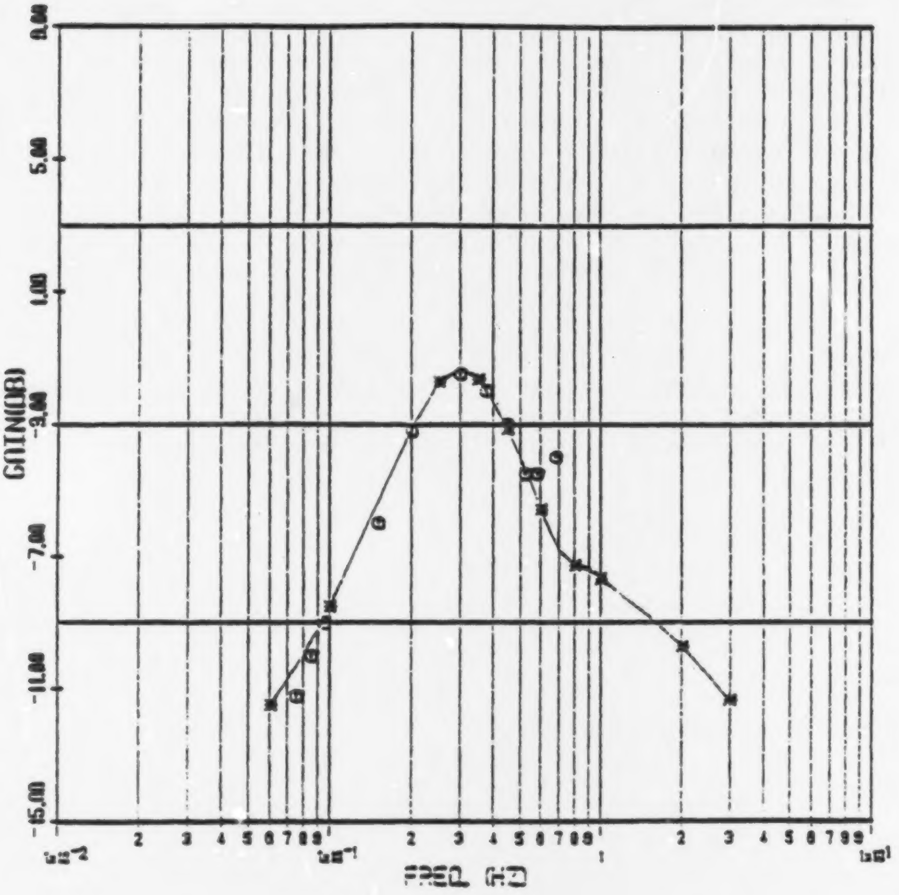

Figure 7 FRIGG Loop Test Run No. 362008, Transfer Function $\frac{\delta\hat{G}/G_0}{\delta\hat{q}'''/q_0'''}$ Gain

0 Measured value

* Calculated value

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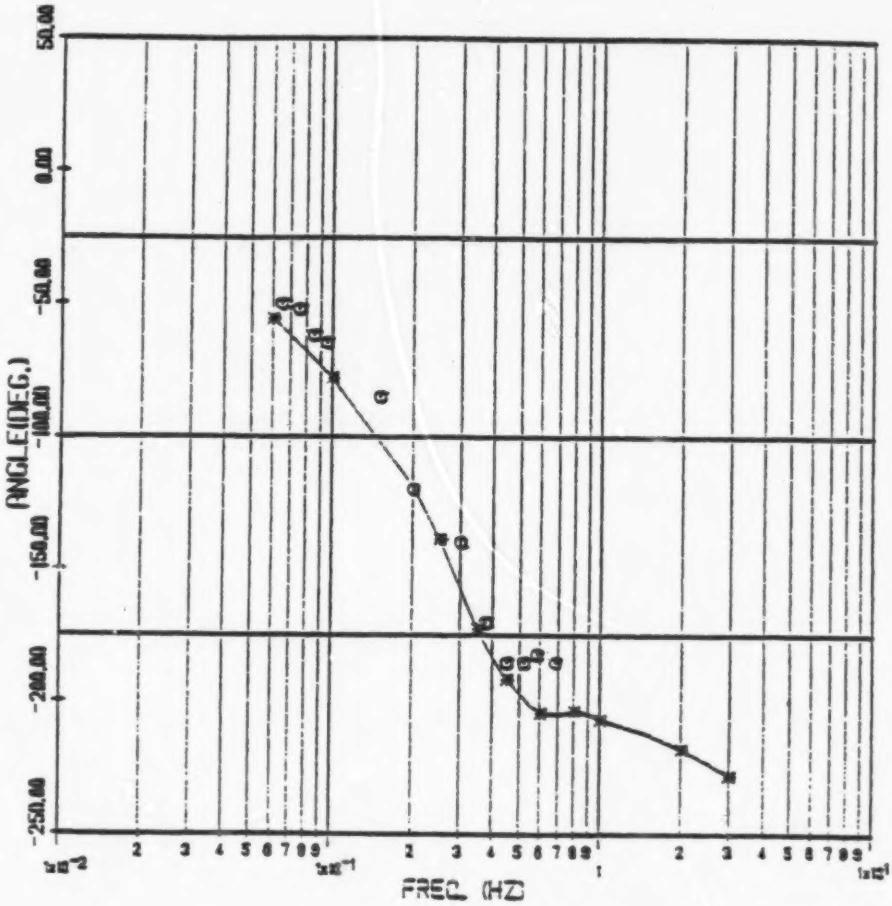

Figure 8 FRIGG Loop Test Run No. 362008, Transfer Function $\frac{\delta\hat{G}/G_o}{\delta\hat{q}'''/q_o'''}$ phase

0 Measured value

* Calculated value

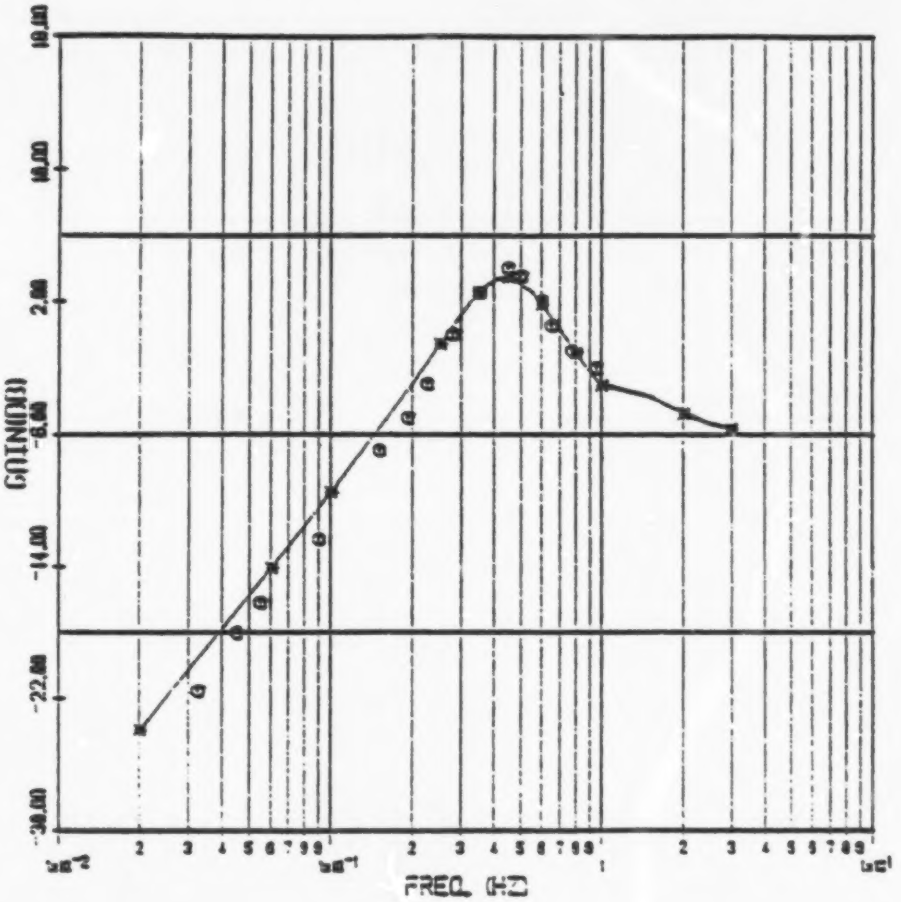

Figure 9 FRIGG Loop Test No. 362016, Transfer Function $\frac{\delta\tilde{G}/G_0}{\delta\hat{q}'''/q_0'''}$ Gain

0 Measured value

* Calculated value

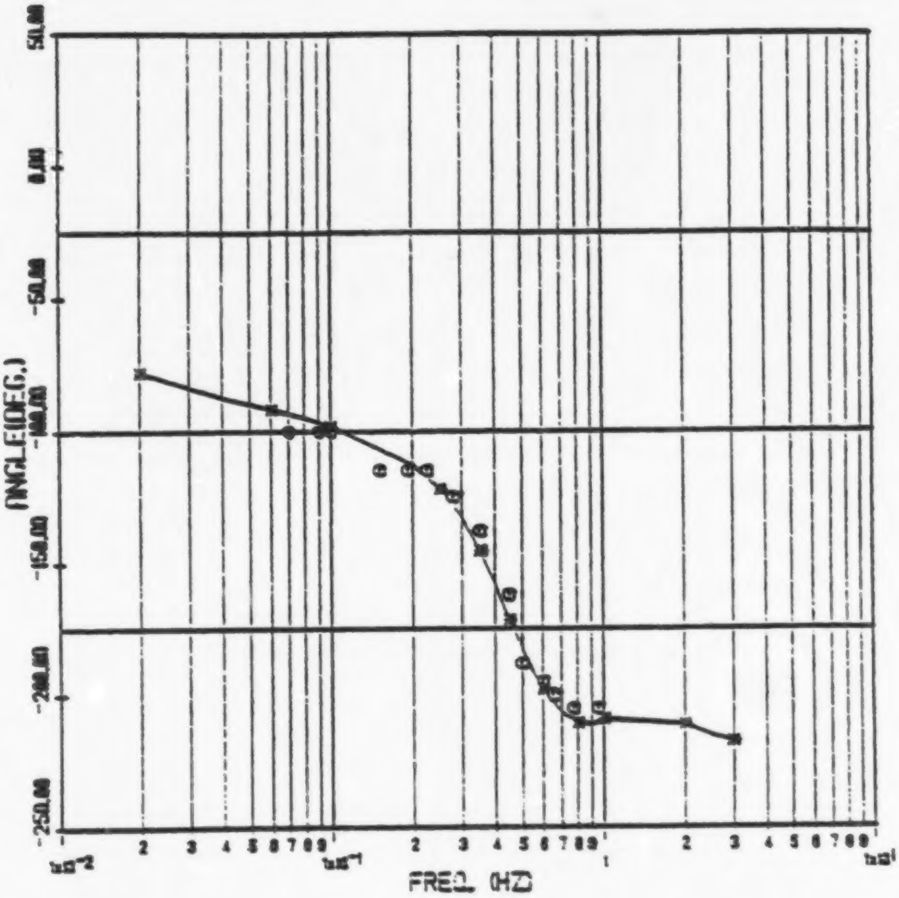

Figure 10 FRIGG Loop Test No. 32016, Transfer Function $\frac{\delta\hat{G}/G_0}{\delta\hat{q}'''/q_0'''}$ Phase

0 Measured value

* Calculated value

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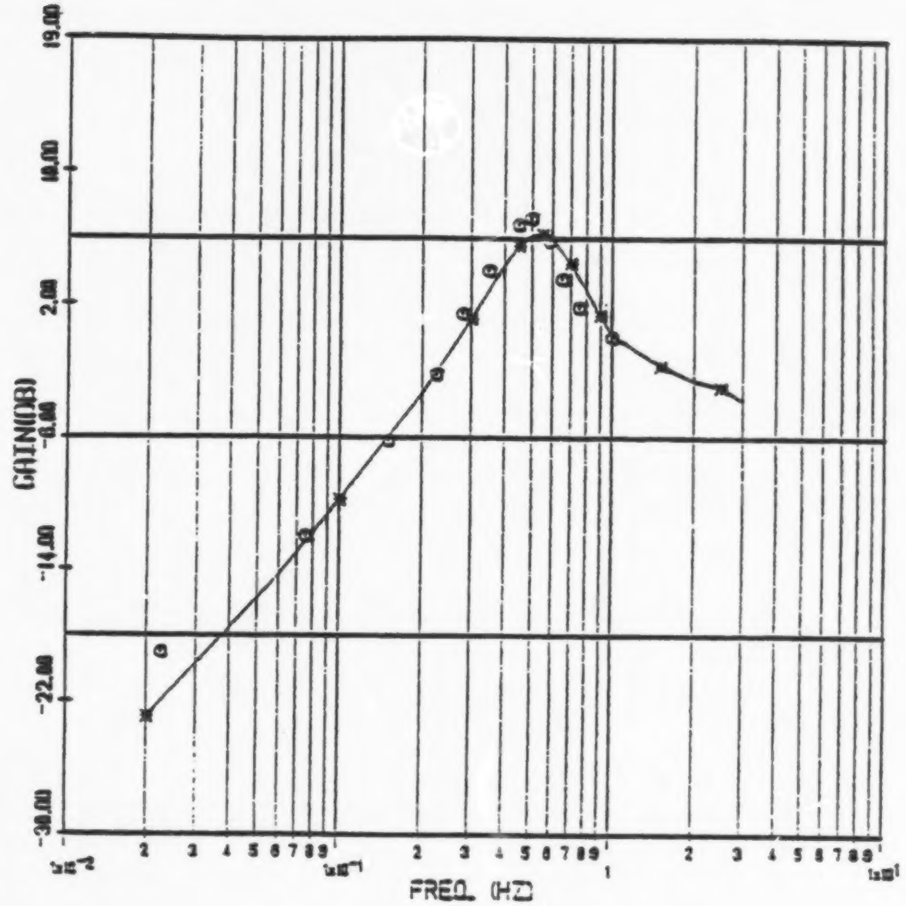

Figure 11 FRIGG Loop Test No. 362022, Transfer Function $\frac{\delta\hat{G}/G_0}{\delta\hat{q}'''/q_0'''}$ Gain

0 Measured value

* Calculated value

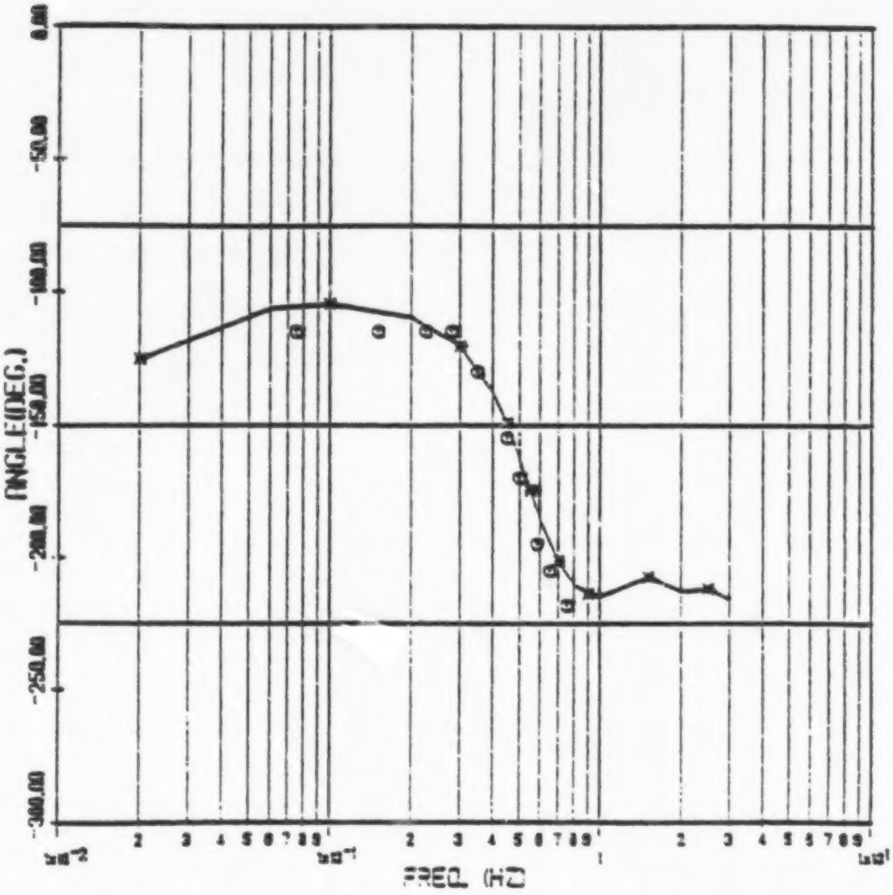

Figure 12 FRIGG Loop Test No. 362022, Transfer Function $\frac{\delta\hat{G}/G_0}{\delta\hat{q}'''/q_0'''}$ Phase

0 Measured value

* Calculated value

CHAPTER 5

APPLICATION OF NUFREQ-NP TO PEACH BOTTOM-2 (PB2) LOW-FLOW STABILITY TESTS

As mentioned before, the main purpose of this study was to develop a fast running digital computer code capable of evaluating the transfer functions of a BWR subject to external pressure perturbations. The purpose of this section is to present the results of comparisons of NUFREQ-NP calculations to the Peach Bottom (PB2) low flow stability tests. The NUFREQ-NP calculations were performed using a point kinetics model for reactor neutronics.

5.1 Peach Bottom-2 Stability Tests

A detailed description of the Peach Bottom-2 plant design, stability test conditions, as well as the experimental results have been published in references 8 and 2, respectively. The test conditions and measurements of importance for the analyses with the NUFREQ-NP code are given in Table 1.

The Peach Bottom-2 Nuclear Power Plant is a BWR/4 type reactor, with a rated thermal power of 3293 MWt. The core contains 764 fuel assemblies and 185 control rods. At the time of the tests (the End-of-Cycle-2), 576 of the fuel assemblies were of the original 7x7 type and 188 of the reload 8x8 type.

The in-core instrumentation consisted of 43 detector strings, each having four local power range monitors (LPRMs), located at four axial levels in the core: A, B, C, D at elevations of 1.5, 4.5, 7.5 and 10.5 feet, respectively. The LPRMs are grouped together into six independent average power range monitor channels (APRM), used to indicate total power and connected to the reactor protection system. Each of the 43 detector strings can be entered by a traversing in-core probe (TIP), to record the detailed axial power distribution.

The stability tests were initiated by running periodic and pseudo-random binary switching (PRBS) small step inputs to the system pressure regulator reference set point. The switching period of the periodic input command signal was 20 seconds, and the minimum switching time of the PRBS signal was 1 second. The magnitude of the pressure set point steps was selected to be approximately 8 psi, which gave a good signal-to-noise ratio in the neutron flux response, and did not cause operational difficulties during testing. The rise time of the reactor pressure response to a pressure regulator step input command was approximately 1.5 seconds.

The reactor operating conditions at which the low-flow core stability testing was conducted are listed in Table 1. At the time of the tests, the core neutron flux and core pressure fluctuations were digitally recorded. The Fourier transform of the autocovariance (power spectral density function) and covariance (cross spectral density function) were calculated numerically using the data acquisition system computer. The cross and power spectral densities were used to determine the system transfer functions. The experimental results are presented, together with NUFREQ-NP results, in the next section.

TABLE 1

Stability Test Conditions

Test Number	Reactor Power		Core Flow Rate		Core Pressure (psia)	Core Inlet Enthalpy (Btu/lb)
	(MWt)	(% Rated)	(10^6 lb/hr)	(% Rated)		
PT1	1995	60.6	52.6	51.3	1000	508.9
PT2	1702	51.7	43.0	42.0	992	505.0
PT3	1948	59.2	38.9	38.0	1005	528.4
PT4	1434	43.5	38.9	38.0	999	507.2

5.2 Application to PB2, Sensitivity Studies

In order to obtain a best estimate model for stability analysis of PB2, a base case was used as the starting point. Due to lack of information, this base case used the best values available. Unfortunately, the uncertainty level of some parameters is fairly large relative to the sensitivity of the results to variations of these parameters.

A number of parameters were investigated in an effort to improve the agreement between the measurements and calculations. These parameters were selected according to the uncertainty which may be associated with their numerical value and the influence they may have on the relevant system response mechanisms. Three parameter groups were identified as having the greatest potential for influencing the results by making adjustments within the range of their uncertainty.

The first of these parameters is the conductance of the gap between the fuel and cladding. As shown in Figs. 13-14, an increase of the gap conductance improves agreement of the response primarily in the low frequency range where it is needed most. This tendency agrees with the results of Hornyik(9).

The second important parameter is the void reactivity coefficient, $C\alpha$. Variations in the void reactivity coefficiennt of ± 20% were studied and the results are shown in Figs. 15-16. These figures indicate that using a larger absolute value of the void reactivity coefficient increases the gain in the intermediate and high frequency ranges ($f > 0.1$ HZ) and the phase within low and intermediate frequency ranges ($f < 0.5$ HZ).

The third important parameter studied was the slip model. The results are presented in Figs. 17-18. It is seen that the drift flux parameters, Co and Vgj, fits the experimental data very well in the frequency range $f > 0.3$ HZ. Similar comparison has also been performed for PT4 case, as shown in Figs. 19-20, the conclusions are the same.

It is encouraging to note that both the location and magnitude of the resonant peak in the Bode plots are well predicted by NUFREQ-NP. This is a significant improvement over the prediction capacity of all other frequency domain computer codes, and implies that the contracting physical phenomena are well modelled in NUFREQ-NP. Moreover, NUFREQ-NP is the only code available which can predict the response of a BWR to excitation in external pressure. All other codes, including NUFREQ-NP, must infer equivalent information (i.e., decay ratio) by curve fitting procedures.

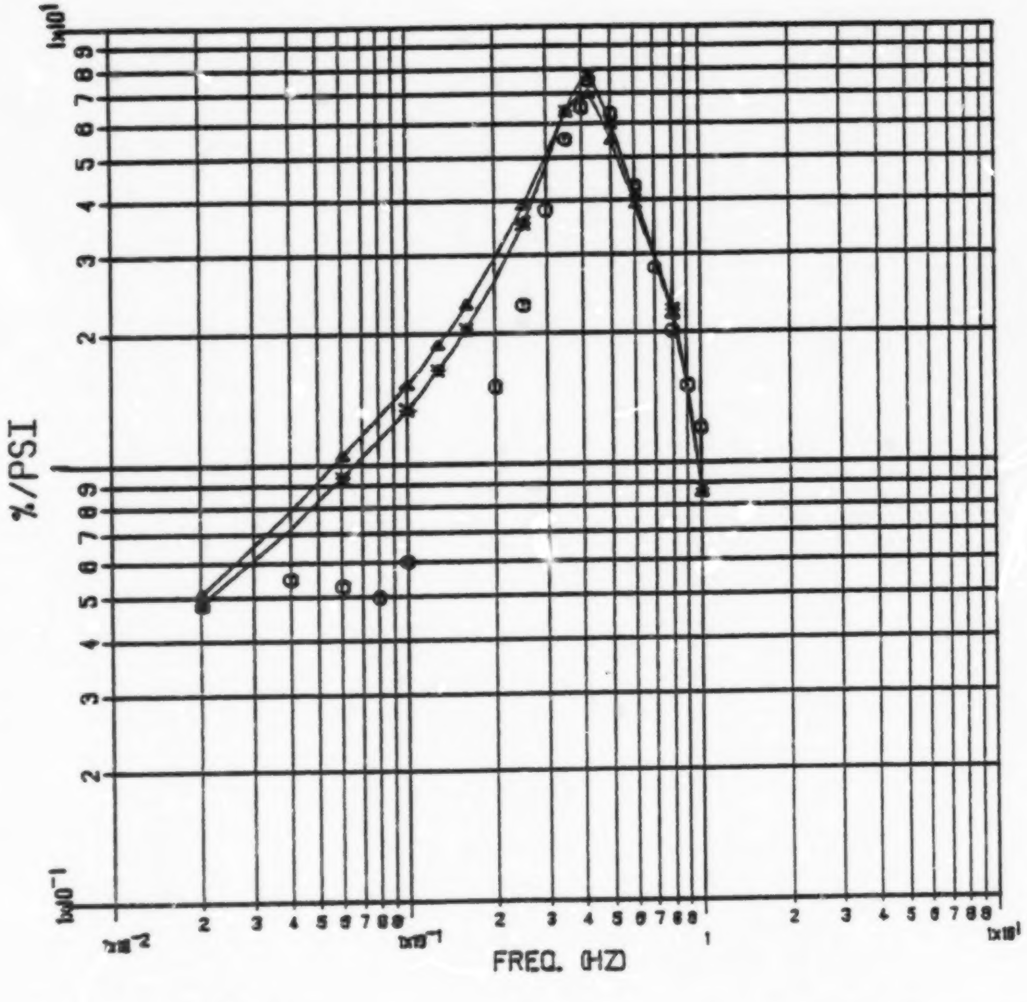

Figure 13 Gain of Average Neutron Flux/Core Pressure Transfer Function for PT3 case with various values for the Gap Conductance (G_c)

O Experimental data

* NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), $C\alpha$ = -0.080, C_o = 1.1560, V_{gj} = 1.1748 (ft/sec)

Δ NUFREQ-NP with G_c = 1000 (Btu/hr - ft^2 - °F), $C\alpha$ = -0.080, C_o = 1.1560, V_{gj} = 1.1748 (ft/sec)

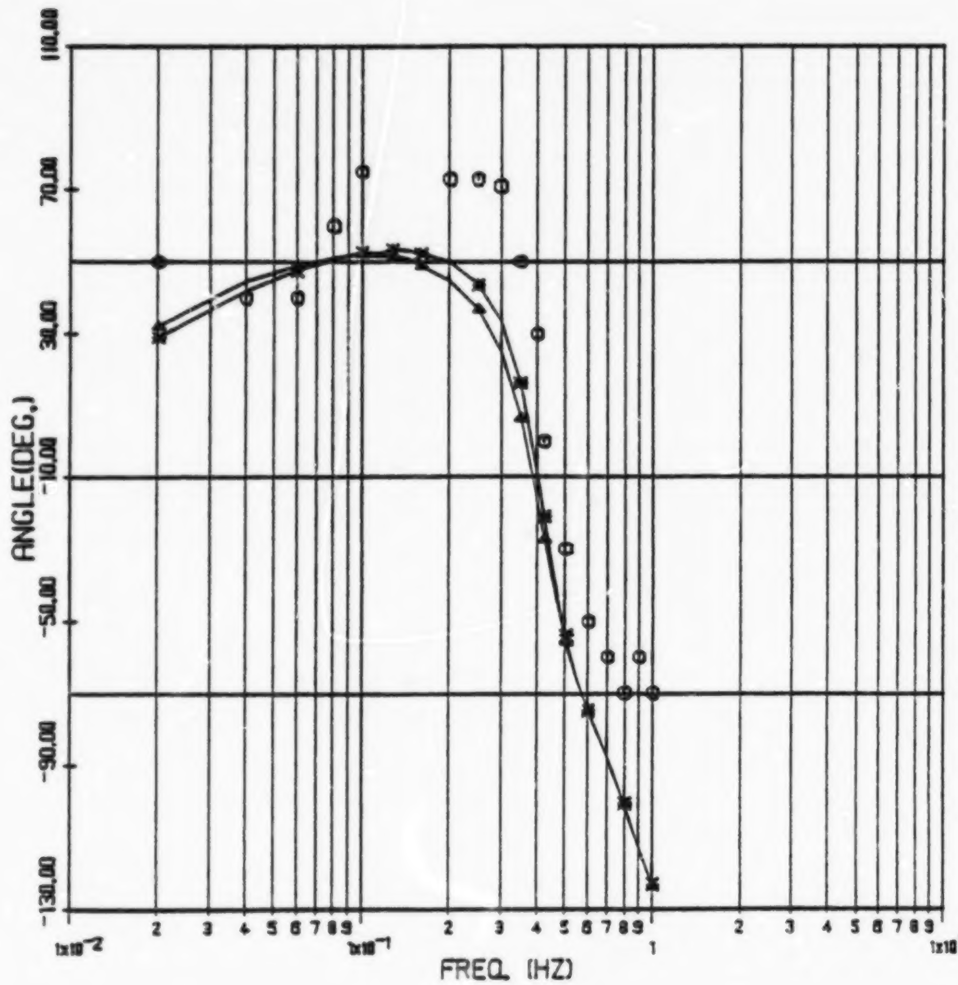

Figure 14 Phase of Average Neutron Flux/Core Pressure Transfer Function for PT3 case with various values for the Gap Conductance (G_c)

O Experimental data

* NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), $C\alpha$ = -0.080, C_0 = 1.1560, V_{gj} = 1.1748 (ft/sec)

Δ NUFREQ-NP with G_c = 1000 (Btu/hr - ft^2 - °F), $C\alpha$ = -0.080, C_0 = 1.1560, V_{gj} = 1.1748 (ft/sec)

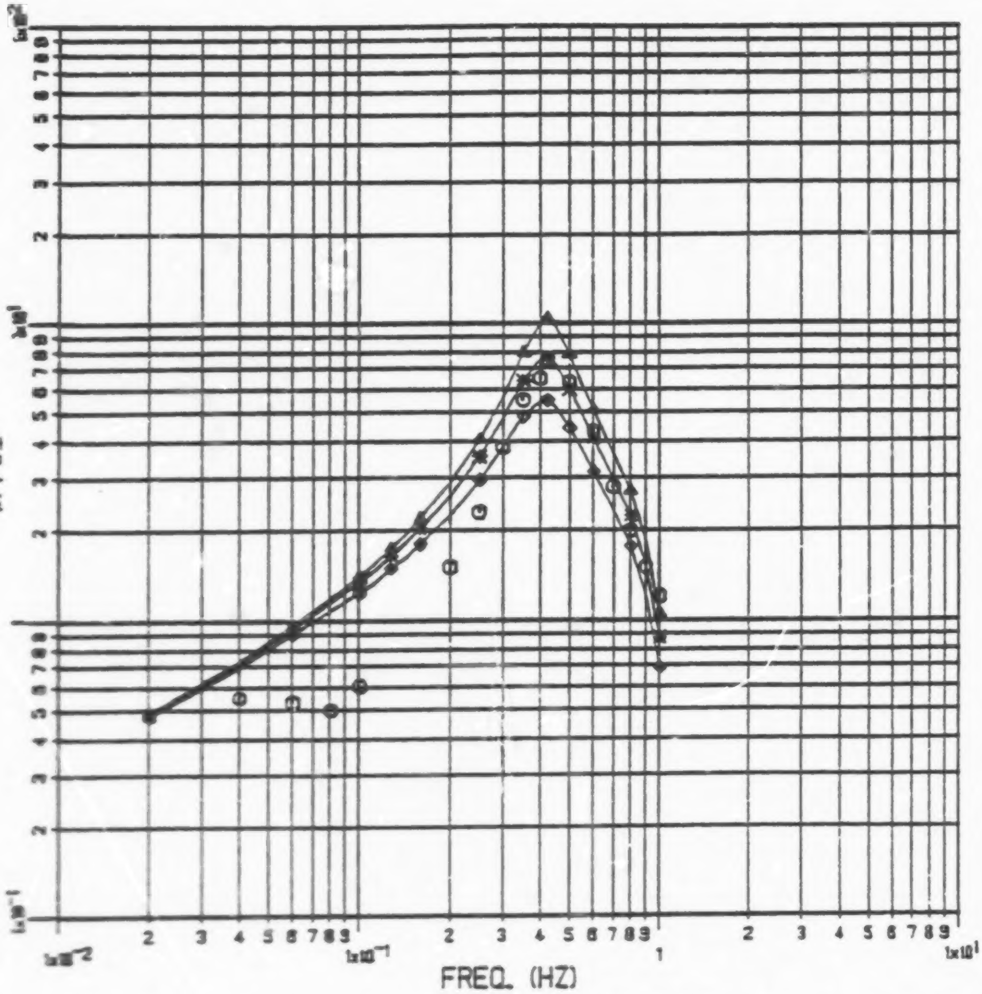

Figure 15 Gain of Average Neutron Flux/Core Pressure Transfer Function for PT3 case with various void coefficients (Cα)

O Experimental data

NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), Cα = -0.064, C_o = 1.156, V_{gj} = 1.1748 (ft/sec)

* NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), Cα = -0.080, C_o = 1.156, V_{gj} = 1.1748 (ft/sec)

Δ NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), Cα = -0.096, C_o = 1.156, V_{gj} = 1.1748 (ft/sec)

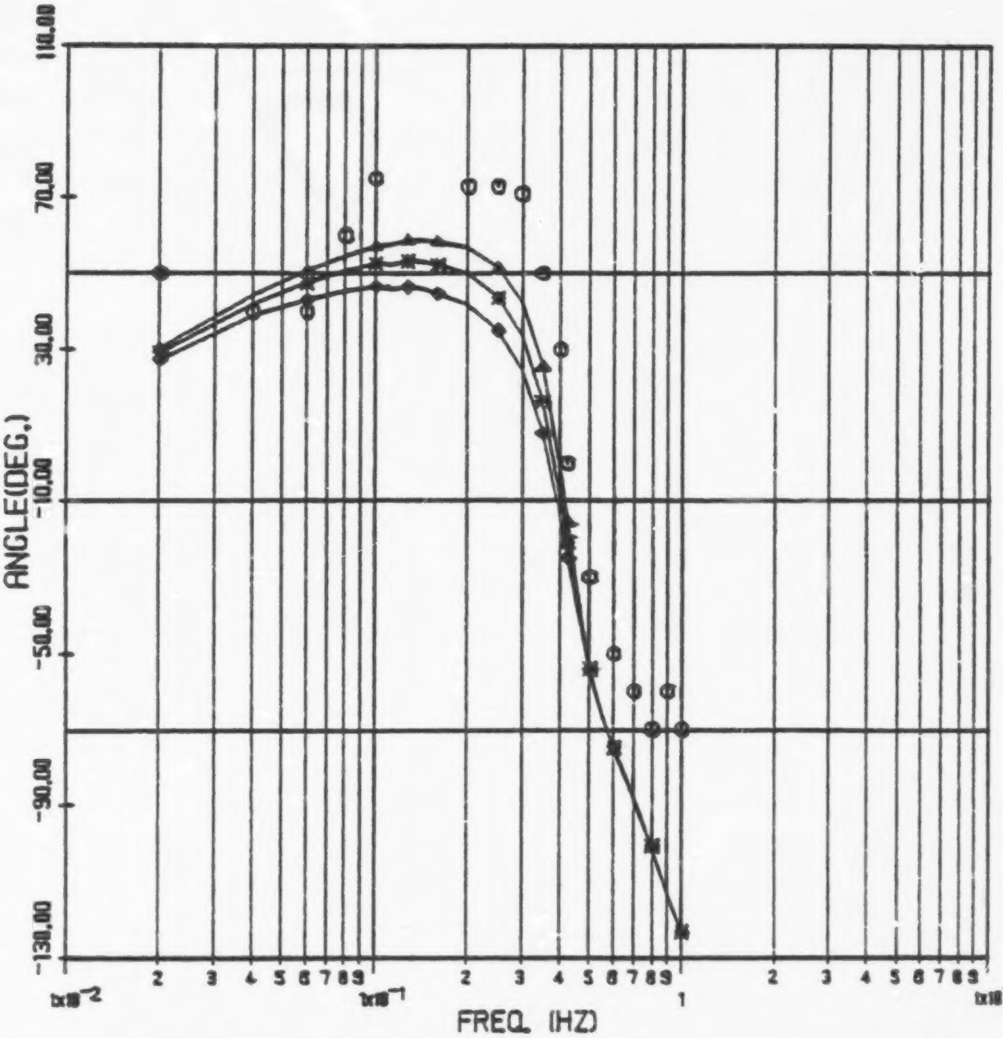

Figure 16 Phase of Average Neutron Flux/Core Pressure Transfer Function for PT3 case with various void coefficients (Cα)

O Experimental data

NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), Cα = -0.064, C_o = 1.156, V_{gj} = 1.1748 (ft/sec)

* NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), Cα = -0.080, C_o = 1.156, V_{gj} = 1.1748 (ft/sec)

Δ NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), Cα = -0.096, C_o = 1.15 6, Vgj = 1.1748 (ft/sec)

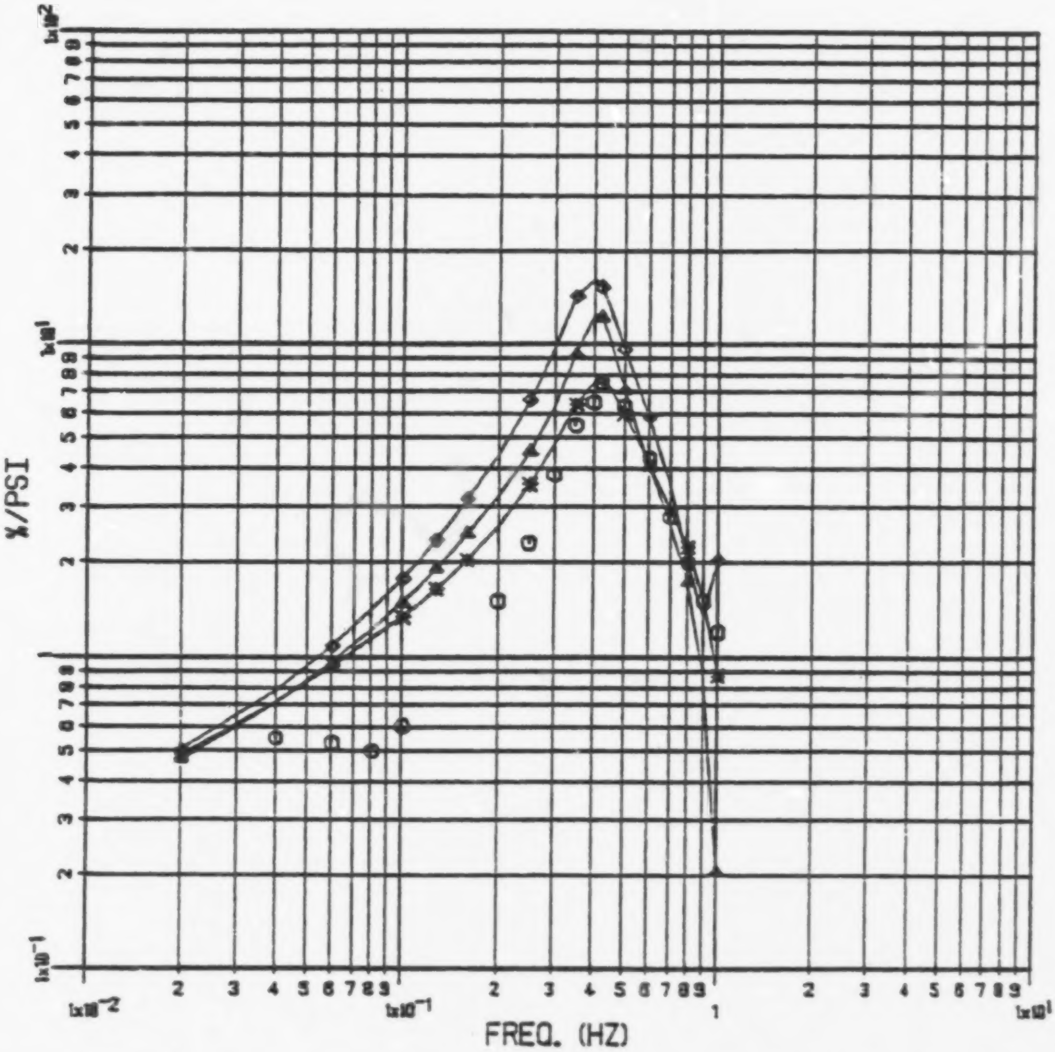

Figure 17 Gain of Average Neutron Flux/Core Pressure Transfer Function for PT3 case with various slip models

O Experimental data

* NUFREQ-NP with G_C = 2000 (Btu/hr - ft^2 - °F), $C\alpha$ = -0.080, C_0 = 1.1560, V_{gj} = 1.1748 (ft/sec)

Δ NUFREQ-NP with G_C = 2000 (Btu/hr - ft^2 - °F), $C\alpha$ = -0.080, C_0 = 1.0, V_{gj} = 1.1748 (ft/sec)

NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), $C\alpha$ = -0.080, variable C_0, Vgj^C

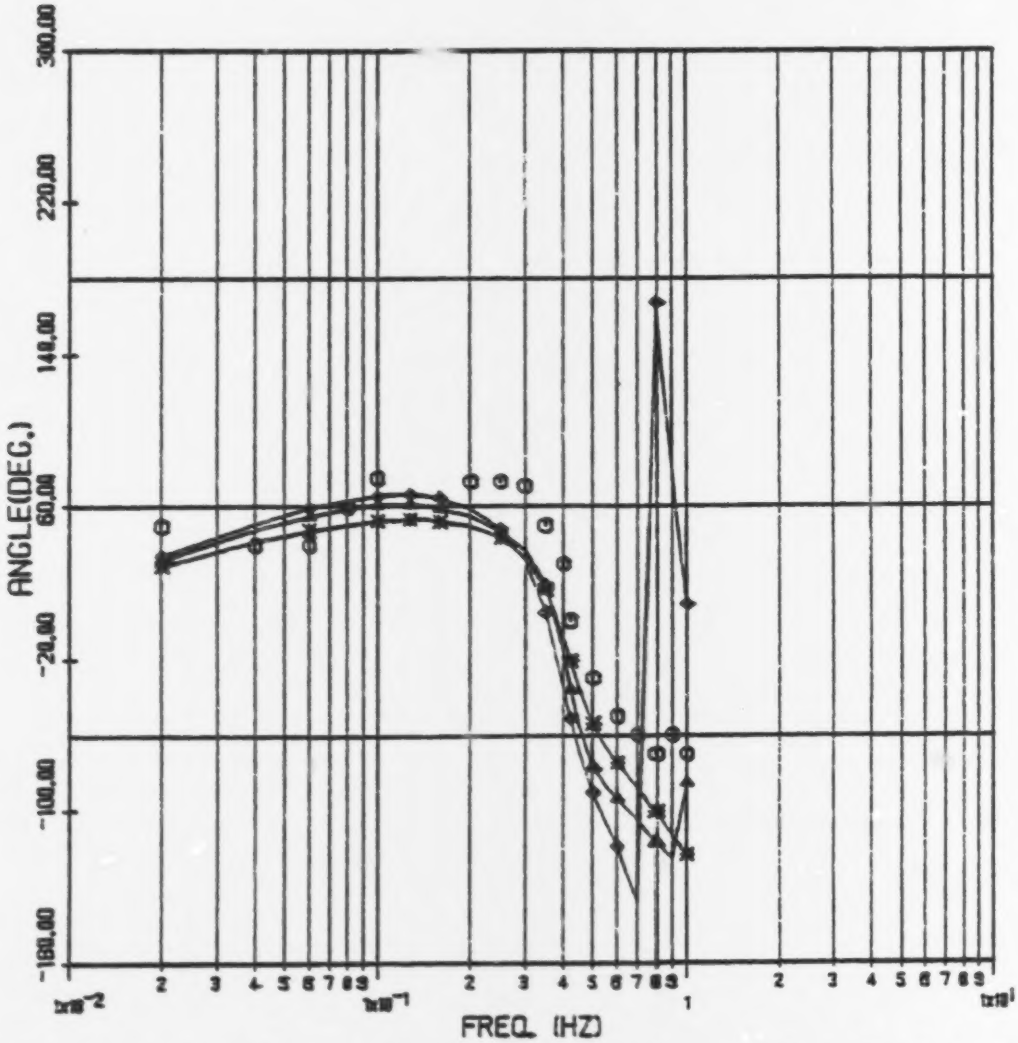

Figure 18 Phase of Average Neutron Flux/Core Pressure Transfer Function for PT3 case with various slip models

O Experimental data

★ NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), $C\alpha$ = -0.080, C_o = 1.1560, V_{gj} = 1.1748 (ft/sec)

Δ NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), $C\alpha$ = -0.080, C_o = 1.0, V_{gj} = 1.1748 (ft/sec)

NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), $C\alpha$ = -0.080, variable C_o, V_{gj}

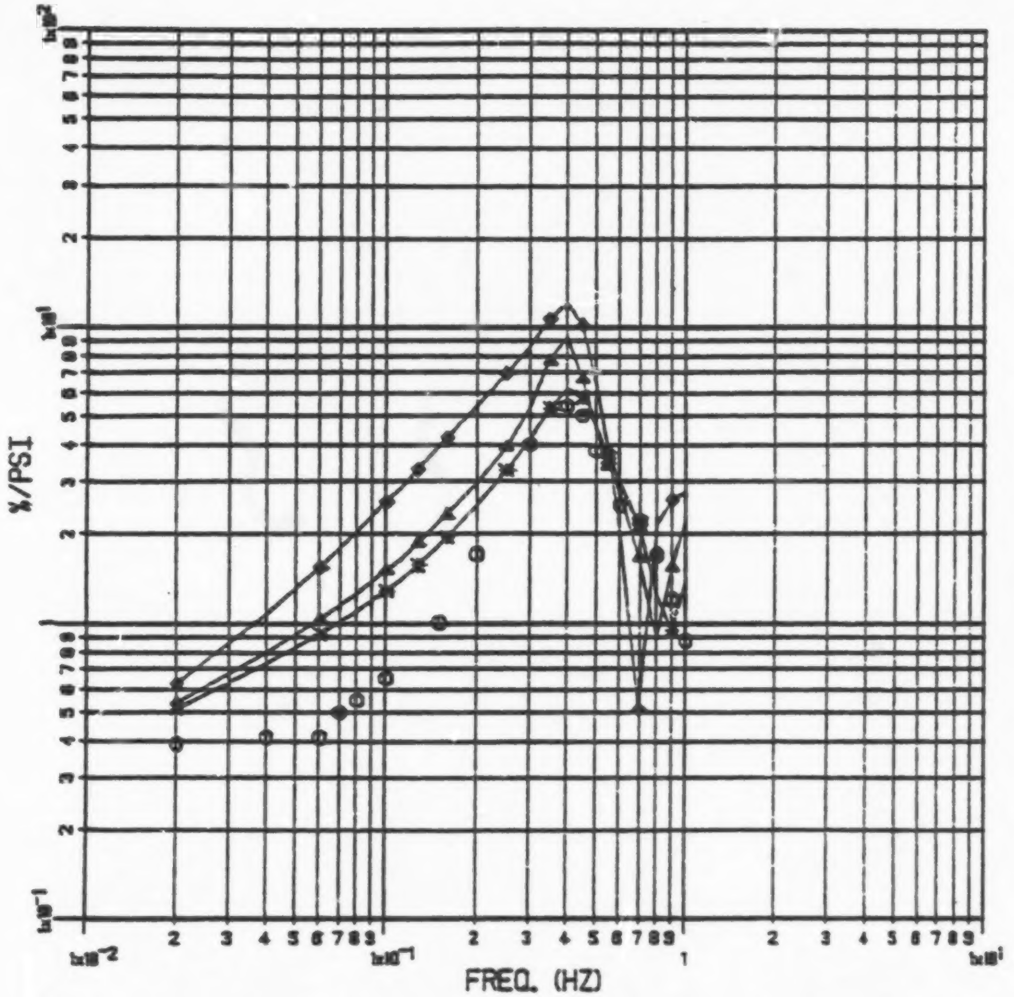

Figure 19 Gain of Average Neutron Flux/Core Pressure Transfer Function for PT4 case with various slip models

O Experimertal data

* NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), $C\alpha$ = -0.05884, C_0 = 1.1564, V_{gj} = 1.1914 (ft/sec)

Δ NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), $C\alpha$ = -0.05884, C_0 = 1.0, V_{gj} = 1.1914 (ft/sec)

NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), $C\alpha$ = -0.05884, variable C_0, V_{gj}

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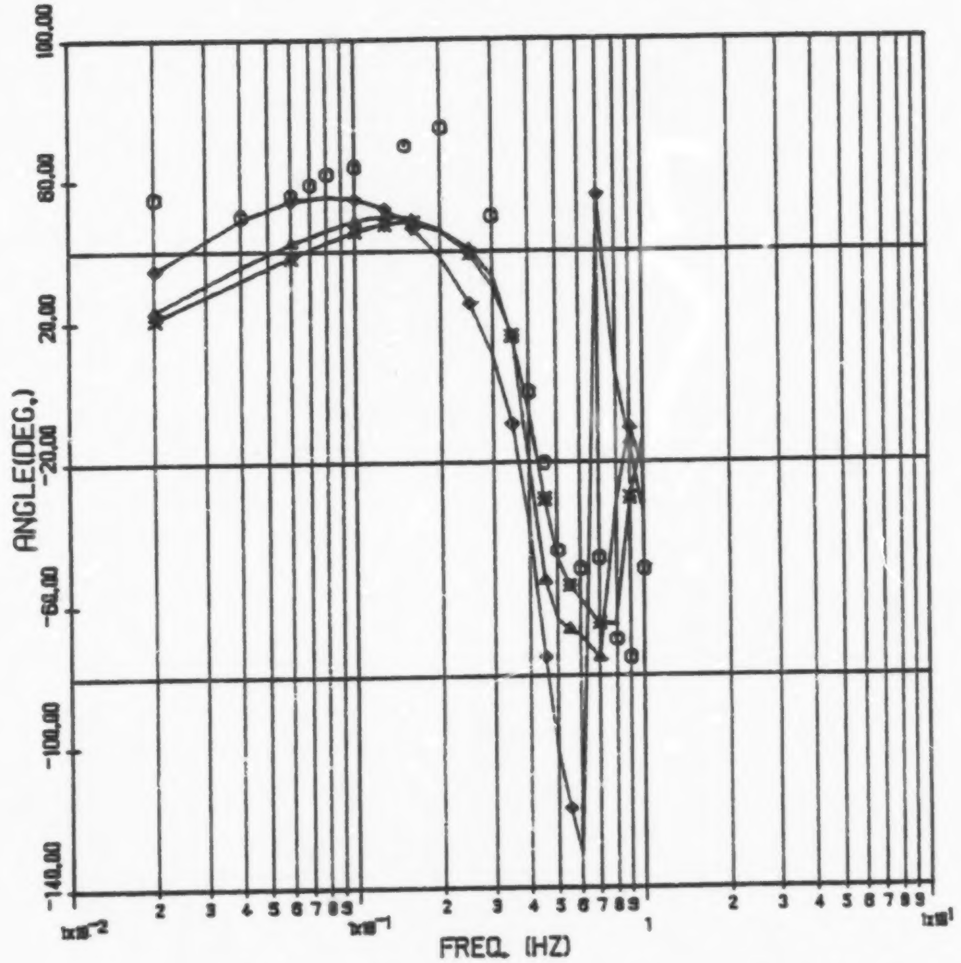

Figure 20 Phase of Average Neutron Flux/Core Pressure Transfer Function for PT4 case with various slip models

0 Experimental data

* NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), Cα = -0.05884, C_o = 1.1564, V_{gj} = 1.1914 (ft/sec)

Δ NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), Cα = -0.05884, C_o = 1.0, V_{gj} = 1.1914 (ft/sec)

NUFREQ-NP with G_c = 2000 (Btu/hr - ft^2 - °F), Cα = -0.05884, variable C_o, V_{gj}

CHAPTER 6

SUMMARY, CONCLUSION, AND RECOMMENDATIONS FOR FUTURE WORK

The analytical approach used in NUFREQ-N(1) has been extended to accommodate system pressure perturbation as an external forcing function. This allows for the direct comparison to recent BWR stability data. This is a significant advance in technology, since no other frequency domain linear stability code has this capability.

Although the algebra involved in accommodating system pressure perturbations was nontrivial, the final results were elegant in that in each case, they involved only the addition of another transfer function. Thus the basic simplicity of the matrix analysis employed is unaltered by accommodating this type of excitation.

Comparisons of NUFREQ-NP with reliable out-of-core stability data from the FRIGG loop experiments indicated that NUFREQ-NP retains and, in fact, improves the predictive capabilities of NUFREQ-N. More importantly, direct comparisons with Peach Bottom data indicated good agreement in that within the uncertainty of the input data, both the location and magnitude of the peak was well predicted. It is significant that good agreement of this type was achieved with a point (neutron) kinetics model. Past experience(4) has indicated that even better agreement may be expected if one is willing to pay the cost of running with the multi-dimensional reactor kinetics models.

It appears that NUFREQ-NP is suitable for use in BWR stability analysis. It should be noted, however, that the results are somewhat sensitive to the input data and options chosen. Thus care should go into these choices, particularly the core's nuclear data.

Even though much of the input and user's instruction for NUFREQ-NP are the same as for NUFREQ-N, and thus have been previously tabulated(1), they are reproduced in this report to aid the user. Specifically, the following NUFREQ-NP user's guides are provided:

Appendix I - Flow chart

Appendix J - Subroutines and functions

Appendix K - Input/output description

Appendix L - Sample problem

Appendix M - NUFREQ-NP FORTRAN listing

It should be noted that NUFREQ-NP has been written in FORTRAN-IV and run on an IBM-3081 computer.

Recommendations for Future Work

Although NUFREQ-NP is currently the most advanced linear stability code in existence, improvements are needed in order to accommodate some off-normal BWR modes of operation, and to fully utilize its inherent capabilities.

In particular, the following improvements are needed:

(1) The development and implementation of a dual loop jet pump model are capable of predicting the effect of single loop operation on BWR stability.

(2) The BWR stability margins should be evaluated by the use of the multi-input/multi-output (MIMO) techniques developed by Balaram, et.al.(6). This requires evaluation of the singular values of the complex system matrix, $\underline{H}$.

(3) The numerical technique used in the multi-dimensional reactor neutronic models should be improved to reduce computer run time when this option is used.

(4) The ability to easily handle control oscillator experiments should be included into the multi-dimension reactor neutronics package.

(5) The void dependent drift-flux parameters should be rigorously treated (i.e., $dC_0/d\langle\alpha\rangle$ and $dV_{gj}/d\langle\alpha\rangle$ terms should be considered in the expression for kinematic wave speed, C_K.

Acknowledgments

The authors wish to gratefully acknowledge the initial analysis on the problem of external pressure perturbations done by Steven Antal (KAPL), and the help freely given by Dr. Goon Park. In addition, the financial support and technical guidance of Dr. Novak Zuber is acknowledged and appreciated. Indeed, it was Dr. Zuber who first realized the need to accommodate external pressure perturbations into the NUFREQ codes.

NOMENCLATURE

a = Reynolds number exponent, typically around 0.8

a = Parameter defined in Fig. 3

A_{D1} = Cross-sectional flow area of downcomer 1

A_{DC} = Cross-sectional flow area of downcomer 2

A_h = Cross-sectional area of heated wall

$A_{H,LP}$ = Heat transfer area of lower plenum

A_p = Cross-sectional flow area of upper plenum (region II)

A_R = Cross-sectional flow area of riser

A_{XS} = Cross-sectional flow area of coolant channel

A_{SS} = Flow area of steam separator

$A(z)$ = Flow area at z position in upper plenum region II

$\tilde{A}$ = Equivalent liquid flow area in steam separator

C_{pf} = Specific heat of saturated liquid at constant pressure

$C_{p\ell}$ = Specific heat of liquid at constant pressure

C_{pc} = Specific heat of cladding at constant pressure

C_{pF} = Specific heat of fuel pellet at constant pressure

C_o = Void concentration parameter

C_K = Kinematic wave speed

C_1 = Parameter for two-phase friction multiplier (see Eq. (F-27))

C_2, C = Parameter for two-phase friction multiplier (see Eq. (F-27))

$C_{1,UP}$ = Complex function defined in Eq. (2.109)

$C_{2,UP}$ = Complex function defined in Eq. (2.111)

C_α = Core-average void reactivity coefficient

d_1 = Thickness of pressure vessel

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D_H = Hydraulic diameter

f = Darcy-Weisbach friction factor

F = Complex function defined in Eq. (2.144)

g = Gravitational acceleration

g_c = Gravitational conversion factor (32.17 lbm-ft/lbf-s^2)

g_p = Parameter defined in Eq. (2.191)

g_p^* = Parameter defined in Eq. (2.196)

G = Mass flux

$G' = \frac{G^2}{\langle\bar{\rho}\rangle}$

ΔG = Parameter defined in Eq. (2.190)

h_f = Specific enthalpy of saturated liquid

h_g = Specific enthalpy of saturated vapor

h_ℓ = Specific enthalpy of liquid phase

$h_{\ell,k,o}$ = h_ℓ in K^{th} node at steady-state

$h_{\ell d}$ = Specific enthalpy of liquid phase at void departure point

h_{in} = Coolant enthalpy at channel inlet

H_o = Condensation parameter in the subcooled boiling

H_g = Gap conductance in fuel rod

$H_{1\phi}$ = Single-phase heat transfer coefficient

$H_{2\phi}$ = Two-phase heat transfer coefficient

$H_i(s)$ = Transfer functions defined in Eqs. (2.19)-(2.22)

H_k' = Complex function defined in Eq. (2.23)

J = Mechanical equivalent of heat, 778 ft-lbf/Btu

j_ℓ = Volumetric flux of liquid phase

j_{in} = Volumetric flux at channel inlet

$j_{i,o}$ = Steady-state volumetric flux at i^{th} channel inlet

$\langle j_p \rangle$ = Cross-section average of volumetric flux in upper plenum

K = Parameter in nucleate boiling heat transfer coefficient

K_j = Total number of nodes in j^{th} channel

K_m = Local loss coefficient associated with m^{th} control volume in ex-core single-phase (liquid) region

K_{sep} = Local loss coefficient associated with steam separator

$K_{spacer,m}$, $K_{s,m}$ = Local loss coefficient associated with m^{th} spacer

$\tilde{\ell}$ = Equivalent liquid flow spiraling length in steam separator

ℓ_{sep} = Length of steam separator

L = Total number of single-phase nodes in channel

L_H = Heated channel length

L_R = Position of inlet of lower plenum

L_{D1} = Length of downcomer control volume 1

L_{DC} = Position of "mini" mix control volume for recirculation loop dynamics

L_w = Length of saturated water region in steam dome

ΔL_R = $L_R - L_{DC}$

$\Delta L_{f,m}$ = Flow path length for m^{th} control volume in ex-core single-phase (liquid) region

$\Delta L_{g,m}$ = Vertical length for m^{th} control volume in ex-core single-phase (liquid) region

m = Parameter in nucleate boiling heat transfer coefficient

M_s = Total number of spacers in single-phase (liquid) region

M_t = Total number of spacers in channel

M_k = Total number of spacers in K^{th} node

M_{Lp} = Total coolant mass in lower plenum

N = Total number of channels

N_t = Total number of nodes in each channel

p = System pressure

P_H = Heated perimeter

$P_{H,v}$ = Heated perimeter for vessel

Pe = Peclet number

p_ℓ = Liquid phase pressure

Δp_J = Jet pump head gain

$\Delta p_{1\phi}$ = Pressure drop in single-phase region of coolant channel

$\Delta p_{2\phi}$ = Pressure drop in two-phase region of coolant channel

Δp_{SS} = Pressure drop in steam separator

q'' = Heat flux

q''' = Volumetric heat generation rate

r_0 = Parameter defined in Fig. 3

R_{p1} = Vertical position at inlet of upper plenum region II

R_{p2} = Vertical position at outlet of upper plenum region II

s = Laplace transform variable

S_p = Parameter defined in Eq. (2.219)

$$S_{DG} = \left(\frac{\rho_f - \overline{\langle\rho\rangle}}{\overline{\langle\rho\rangle} - \rho_g}\right)\left(\frac{\rho_f\,\rho_g}{\overline{\langle\rho\rangle}}\right)(V'_{gj})^2$$

t = Time

$x(s)$ = Complex function defined in Eq. (2.298)

T_c = Cladding temperature

T_F = Fuel pellet temperature

T_∞ = Coolant temperature

T_o = Environmental temperature for pressure vessel

T_{bulk}^{in} = Temperature in downcomer

$u_{\ell,k}$ = Liquid phase velocity in K^{th} node

v_ℓ = Specific volume of liquid phase

v_f = Specific volume of saturated liquid

v_g = Specific volume of vapor phase

$v_{\ell g}$ = $v_g - v_\ell$

v_{fg} = $v_g - v_f$

$\overline{V}_1'$ = Parameter defined in Eq. (2.192)

$\overline{V}_2'$ = Parameter defined in Eq. (2.193)

V_h = Volume of heated wall

$V(z)$ = Volume defined in Eq. (2.137)

V_{gj} = Drift velocity

V_{gj}' = $V_{gj} + (C_o - 1) \langle j \rangle$

w_e = Mass flow rate of saturated water flow out of control volume 1

w_R = Mass flow rate of total two-phase mixture flow out of riser

w_{fw} = Mass flow rate of feedwater

w_{sw} = Mass flow rate of saturated water flow from steam separator into control volume 1

w_{mix} = $w_e + w_{fw}$

w_{core} = Total mass flow rate

w_o = $w_{core,o}$

$\langle x \rangle$ = Cross-sectional flow quality

z = Axial position

z_d = Void departure point

Z_p = Complex function defined in Eq. (A-13)

Z_1 = Complex function defined in Eq. (2.90)

Z_2 = Complex function defined in Eq. (2.90)

Z_3 = Complex function defined in Eq. (A-14)

z_m = Position o m^{th} spacer

z_p^{in} = Vertical position of upper plenum region I

z_p^{out} = Vertical position of upper plenum region II

Δz_p = $z_p^{out} - z_p^{in}$

Δz_R = Length of riser

Greek

$\langle \alpha \rangle$ = Cross-sectional average void fraction

β_p = Volume expansion coefficient

$\beta(s)$ = Transfer function for single-phase (liquid) dynamics

ϵ = Transition parameter from subcooled boiling to bulk boiling

Γ = Vapor generation rate per unit volume

$\Gamma_i(s)$ = Transfer function for single-phase (liquid) dynamics

Γ'_{UP} = Complex function defined in Eq. (2.107)

Γ_R' = Complex function defined in Eq. (2.177)

κ_c = Thermal conductivity in cladding

κ_v = Thermal conductivity in pressure vessel

κ_F = Thermal conductivity in fuel pellet

$\Lambda_i(s)$ = Transfer function for single-phase (liquid) dynamics

μ = Dynamic viscosity

$\pi_i(s)$ = Transfer function for two-phase dynamics

Φ = Two-phase local loss multiplier

$\phi(s)$ = Transfer function for single-phase (liquid) dynamics

$\phi_{\ell o}^2$ = Two-phase friction loss multiplier

ρ_c = Cladding density

ρ_F = Fuel pellet density

ρ_f = Saturated liquid density

ρ_g = Saturated vapor density

ρ_ℓ = Liquid phase density

ρ' = Parameter defined in Eq. (2.189)

$\Delta\rho$ = $\rho_f - \rho_g$

$\langle\overline{\rho}\rangle$ = $\rho_f(1 - \langle\alpha\rangle) + \rho_g\langle\alpha\rangle$

σ = Surface tension

Ω = Characteristic frequency of phase change

$\theta(s)$ = Transfer function for single-phase (liquid) dynamics

$\psi(s)$ = Transfer function for single-phase (liquid) dynamics

ξ = Slope of the pump head-flow curve

ξ_k = Dimensionless position in k^{th} node, defined in Eq. (E-10)

ξ_m = Dimensionless position for m^{th} spacer

Subscripts/Superscripts

o = Steady-state

B = Node for bulk boiling point

d,D = Node for void departure point

DC = Index for downcomer

ext = External

exit = Channel exit

f = Saturated liquid

fw = Feedwater

g = Saturated vapor

in = Inlet of channel

In = Inlet of node

k = Node index

ℓ = Liquid phase

LP = Index for lower plenum

m = Spacer index

m = External loop control volume index

mix = Index for the control volume between downcomer control volume 1 and 2

n = Channel index

OUT = Outlet of node

P,UP = Upper plenum index

R = Riser index

sb = Subcooled boiling

sat = Saturated

v = Reactor vessel

wall = Heater wall

1ϕ = Single-phase

2ϕ = Two-phase

Symbols

$(\bar{\ })$ = Node averaging

$\langle\ \rangle$ = Cross-sectional averaging

$\delta\hat{\langle\ \rangle}$ = Perturb and Laplace transform

$(\ )^t$ = Transpose of a vector or a matrix

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APPENDIX A

HEAT FLUX PERTURBATION

1. Single Phase Region

The heat flux in the single-phase region is given by,

$$q'' = H_{1\phi}(T_{wall} - T_{\infty}) \qquad \text{(A-1)}$$

where the single-phase heat transfer coefficient, $H_{1\phi}$, is obtained from the classical Dittus-Boelter equation,

$$H_{1\phi} = 0.023 \frac{\kappa}{D_H}\left(\frac{\rho_f \, j \, D_H}{\mu}\right)^{0.8} \left(\frac{C_p \, \mu}{\kappa}\right)^{0.4} \qquad \text{(A-2)}$$

Assuming that the pressure dependence of κ, μ, and C_p is negligible, and perturbing and Laplace transforming Eqs. (A-1) and (A-2), we obtain,

$$\delta\hat{q}'' = \frac{q_o''}{H_{1\phi}} \delta\hat{H}_{1\phi} + H_{1\phi,o}(\delta\hat{T}_{wall} - \delta\hat{T}_{\infty}) \qquad \text{(A-3)}$$

$$\delta\hat{H}_{1\phi} = 0.8 \frac{H_{1\phi,o}}{j_o} \delta\hat{j} \qquad \text{(A-4)}$$

Note that $\delta\hat{T}_{\infty}$ can be related to $\delta\hat{h}$ through the following relation,(11)

$$C_p \, \delta\hat{T}_{\infty} = \delta\hat{h} - v_f(1 - \beta_p \, T_{\infty,o}) \, \delta\hat{p} \qquad \text{(A-5)}$$

Combining Eqs. (A-3), (A-4) and (A-5) with Eq. (2.90) yields,

$$\frac{\delta\hat{q}''}{q_o''} = \frac{1}{1 - H_{1\phi,o}Z_1}\left\{0.8 \frac{\delta\hat{j}}{j_o} + \frac{H_{1\phi,o}Z_2}{q''_o} \delta\hat{q}''' - \frac{H_{1\phi,o}}{C_p q_o''} \delta\hat{h} + \left[\frac{H_{1\phi,o} \, v_f}{C_p \, q_o''}(1 - \beta_p \, T_{\infty})\right]\delta\hat{p}\right\} \qquad \text{(A-6)}$$

Equation (A-6) is a generalized form of the corresponding expression used in NUFREQ-N.(1)

2. Two-Phase Region

In the two-phase region, the heat flux is assumed to be of the form,

$$q'' = K(T_{wall} - T_{sat})^m \tag{A-7}$$

where K and m depend on the model used. Specifically, for the models used in NUFREQ-NP, we have:

(a) Jens-Lottes correlation(3)

$$K = \frac{10^6}{3600} \cdot \left[\frac{\text{Exp}(4p/900)}{(60)^4}\right] \quad ; \; m=4 \tag{A-8a}$$

(b) Thom's correlation(3)

$$K = \frac{10^6}{3600} \cdot \left[\frac{\text{Exp}(2p/1260)}{(72)^2}\right] \quad ; \; m=2 \tag{A-8b}$$

Perturbing and Laplace transforming Eq. (A-7) yields,

$$\delta\hat{q}'' = C_1 \, \delta\hat{p} + C_2 \, \delta\hat{T}_{wall} \tag{A-9}$$

where,

$$C_1 \triangleq \frac{q''_o}{K}\frac{dK}{dp} - \frac{m \, q''_o}{(T_{wall} - T_{sat,o})}\left(\frac{dT_{sat}}{dp}\right) \tag{A-10}$$

$$C_2 \triangleq \frac{m \, q''_o}{(T_{wall} - T_{sat})_o} \tag{A-11}$$

Hence, after combining Eq. (A-9) with (2.90), we obtain,

$$\delta\hat{q}'' = Z_p \, \delta\hat{p} + Z_3 \, \delta\hat{q}''' \tag{A-12}$$

where,

$$Z_p \triangleq \frac{C_1}{1 - C_2 Z_1} \tag{A-13}$$

$$Z_3 \triangleq \frac{C_2 Z_2}{1 - C_2 Z_1} \tag{A-14}$$

Again, Eq. (A-12) is a generalization of the corresponding expression used in NUFREQ-N.(1)

APPENDIX B

VOLUMETRIC FLUX AND VOID FRACTION PERTURBATIONS IN SUBCOOLED BOILING REGION

The continuity and void propagation equations for the k-th node are given by,

$$\frac{\partial \langle j \rangle_k}{\partial z} = v_{\ell g}\,\Gamma_k - \frac{\langle \alpha \rangle_k}{\rho_g}\frac{\partial \rho_g}{\partial t} \tag{B-1}$$

and,

$$\frac{\partial \langle \alpha \rangle_k}{\partial t} + (C_K)_k \frac{\partial \langle \alpha \rangle_k}{\partial z} = \frac{\Gamma_k}{\rho_g} - \frac{\langle \alpha \rangle_k}{\rho_g}\frac{\partial \rho_g}{\partial t} - \langle \alpha \rangle_k\, C_{o,k}\frac{\partial \langle j \rangle}{\partial z} \tag{B-2}$$

The vapor generation rate for node-K in the subcooled boiling region is,

$$\Gamma_k = \frac{1}{h_{fg}}\left[\frac{q_k'' P_H}{A_{xs}}\left(\frac{h_{\ell,k} - h_{\ell,d}}{h_f - h_{\ell,d}}\right)\left(\frac{\rho_g h_{fg}}{\rho_\ell(h_f - h_{\ell,k}) + \rho_g h_{fg}}\right)\right.$$
$$\left. - \frac{h_{fg} H_o}{v_{\ell g} C_{p\ell}}\langle \alpha \rangle_k (h_f - h_{\ell,k}) + \frac{1}{J}\frac{\partial p}{\partial t} - \rho_f(1 - \langle \alpha \rangle_k)\frac{dh_f}{dt} - \rho_g \langle \alpha \rangle_k \frac{dh_g}{dt}\right] \tag{B-3}$$

The subcooled liquid energy conservation equation can be written as,

$$\rho_\ell(1 - \langle \alpha \rangle_k)\frac{\partial h_{\ell,k}}{\partial t} + \rho_\ell(1 - \langle \alpha \rangle_k)\, u_{\ell,k}\frac{\partial h_{\ell,k}}{\partial z} = \frac{q_k'' P_H}{A_{xs}} + \frac{1}{J}\frac{\partial p}{\partial t} - \Gamma_k(h_g - h_{\ell,k})$$
$$- \rho_g \langle \alpha \rangle_k \frac{dh_g}{dp}\frac{dp}{dt} \tag{B-4}$$

The kinematic wave speed in k-th node, $(C_K)_k$, is defined as,

$$(C_K)_k = C_{o,k,o}\langle j \rangle_k + V_{gj,k} \tag{B-5}$$

The associated boundary conditions with the above equations are:

(1) At void departure point, (z_d), the subcooled liquid enthalpy satisfies Saha's model. That is,

$$h_{\ell d} = \begin{cases} h_f - 0.0022\,\dfrac{q_d'' D_H C_{p\ell}}{\kappa_\ell}, & \text{for } Pe = \dfrac{G D_H C_{p\ell}}{\kappa_\ell} < 70{,}000 \\[2ex] h_f - 154\,\dfrac{q_d''}{G}, & \text{for } Pe > 70{,}000 \end{cases} \tag{B-6}$$

(2) At bulk boiling boundary, (z_B), the liquid enthalpy is given by,

$$h_{\ell,k} = h_f \tag{B-7}$$

The relevant assumptions are:

(i) All fluid properties except liquid enthalpy ($h_{\ell,k}$) are assumed at their saturation values.

(ii) Nodal-averaged values of void fraction and flow quality are used in solving the subcooled liquid energy equation.

(iii) The nodal-averaged phase change frequency, $\bar{\Omega}$, is used in solving the contiuity and void propagation equations.

For steady-state, Eq. (B-1) reduces to,

$$\frac{d\langle j_o\rangle_k}{dz} = v_{fgo}\,\Gamma_{k,o} \triangleq \bar{\Omega}_{k,o} \tag{B-8}$$

Since $\bar{\Omega}_{k,o}$ is assumed to be space-independent, Eq. (B-8) can be integrated as,

$$\langle j_o\rangle_k = \langle j_o\rangle_k^{IN} + \bar{\Omega}_{k,o}\,(z - z_k) \tag{B-9}$$

Or, using ξ_k coordinates, as defined later in Eq. (E-10), we have,

$$\langle j_o\rangle_k = \frac{1}{C_{o,k,o}}\left[(C_{k,o})_k^{IN}\,\xi_k - V_{gj}\right] \tag{B-10}$$

Similarly, Eq. (B-2) becomes,

$$(C_{K,o})_k\,\frac{d\langle\alpha_o\rangle_k}{dz} = \frac{\Gamma_{k,o}}{\rho_g} - \langle\alpha_o\rangle_k\,C_{o,k,o}\,\frac{d\langle j_o\rangle}{dz} \tag{B-11}$$

Hence, we have,

$$\langle\alpha_o\rangle_k = \frac{\rho_f}{C_{o,k,o}\,\Delta\rho} + \left(\langle\alpha_o\rangle_k^{IN} - \frac{\rho_f}{C_{o,k,o}\,\Delta\rho}\right)\xi_k^{-1} \tag{B-12}$$

By Eq. (B-3), the characteristic frequency of phase change for k^th^ node, $\bar{\Omega}_{k,o}$, is given as,

$$\bar{\Omega}_{k,o} \triangleq v_{fgo}\,\Gamma_{k,o} = \frac{\Delta\rho\, P_H\, q''_{k,o}}{A_{xs}\,\rho_f(h_f - \bar{h}_{\ell d,o})}\left[\frac{\bar{h}_{\ell,k,o} - h_{\ell d,o}}{\{\rho_g\, h_{fg} + \rho_f(h_f - \bar{h}_{\ell,k,o})\}}\right] - \frac{H_o\langle\bar{\alpha}_o\rangle_k}{C_{pf}}(h_f - \bar{h}_{\ell,k,o}) \qquad \text{(B-13)}$$

The steady-state distribution of the liquid phase enthalpy in the subcooled boiling region is given by,

$$G_o\, v_{fg}\,(1 - \langle\bar{\alpha}_o\rangle_k)\,\frac{dh_{\ell,k,o}}{dz} = \frac{q''_{k,o}\, P_H\, v_{fg}}{A_{xs}} - \bar{\Omega}_{k,o}\,(h_g - h_{\ell,k,o}) \qquad \text{(B-14)}$$

In terms of ξ_k-coordinates, Eq. (B-14) becomes,

$$\frac{dh_{\ell,k,o}}{d\xi_k} - b_{2,k}\, h_{\ell,k,o} = b_{3,k} \qquad \text{(B-15)}$$

where,

$$b_{2,k} \triangleq \frac{(C_{K,o})_k^{IN}}{G_o\, v_{fg}\, C_{o,k,o}\,(1 - \langle\bar{\alpha}_o\rangle_k)} \qquad \text{(B-16)}$$

$$b_{3,k} \triangleq \frac{\dfrac{q''_{k,o}\, P_H\, v_{fg}}{A_{xs}} - \bar{\Omega}_{k,o}\, h_g}{G_o\, v_{fg}\,(1 - \langle\bar{\alpha}_o\rangle_k)\,\dfrac{C_{o,k,o}\,\bar{\Omega}_{o,k}}{(C_{K,o})_k^{IN}}} \qquad \text{(B-17)}$$

Integrating Eq. (B-15) yields,

$$h_{\ell,k,o} = b_{5,k}\, e^{b_{2,k}\,\xi_k} + b_{4,k} \qquad \text{(B-18)}$$

where,

$$b_{4,k} \triangleq -\frac{b_{3,k}}{b_{2,k}} \qquad \text{(B-19)}$$

$$b_{5,k} \triangleq (h^{IN}_{\ell,k,o} - b_{4,k})\, e^{-b_{2,k}} \qquad \text{(B-20)}$$

Since $\langle j_o\rangle_k$, $\langle\alpha_o\rangle_k$, $\bar{\Omega}_{k,o}$ and $h_{\ell,k,o}$ are coupled, they must be evaluated by simultaneously solving Eqs. (B-10), (B-12), (B-13), and (B-18). To do this, an iterative technique can be used.

Considering the vapor generation rate, Eq. (B-3), we have,

$$\Gamma_k = \frac{1}{h_{fg}} \left\{\frac{q''_{sb,k}\, P_H}{A_{xs}} + \left[\frac{1}{J}\frac{dp}{dt} - \rho_f(1 - \langle\alpha\rangle_k)\frac{dh_f}{dt} - \rho_g \langle\alpha\rangle_k \frac{dh_g}{dt}\right]\right\} \qquad \text{(B-21)}$$

where,

$$\frac{q''_{sb,k}\, P_H}{A_{xs}} \triangleq \frac{q''_k\, P_H}{A_{xs}} \left[\frac{h_{\ell,k} - h_{\ell d}}{h_f - h_{\ell d}}\right] \left[\frac{\rho_g\, h_{fg}}{\rho_f(h_f - h_{\ell,k}) + \rho_g\, h_g}\right]$$

$$- \frac{h_{fg}\, H_o}{v_{fg}\, C_{pf}} \langle\alpha\rangle_k\, (h_f - h_{\ell,k}) \qquad \text{(B-22)}$$

Perturbing and Laplace Transforming Eq. (B-21) yields,

$$\delta\hat{\Gamma}_k = \frac{1}{v_{fg}}\, \delta\hat{\Omega}_{q,k} + (\gamma_{3,sb} + \langle\alpha_o\rangle_k\, \gamma_2)\, \delta\hat{p} \qquad \text{(B-23)}$$

where,

$$\delta\hat{\Omega}_{q,k} \triangleq \frac{v_{fg}\, P_H}{h_{fg}\, A_{xs}}\, \delta\hat{q}''_{sb,k} \qquad \text{(B-24)}$$

$$\gamma_2 \triangleq \frac{s}{h_{fg}} \left(\rho_f \frac{dh_f}{dp} - \rho_g \frac{dh_g}{dp}\right) \qquad \text{(B-25)}$$

$$\gamma_{3,sb} \triangleq - \frac{q''_{sb,k,o}\, P_H}{h^2_{fg}\, A_{xs}} \frac{dh_{fg}}{dp} + \frac{s}{h_{fg}} \left(\frac{1}{J} - \rho_f \frac{dh_f}{dp}\right) \qquad \text{(B-26)}$$

In order to simplify the analysis, we can approximate $\delta\hat{\Omega}_{q,k}$ by its node-average value given by,

$$\delta\hat{\bar{\Omega}}_{q,k} = \frac{v_{fg}\, P_H}{h_{fg}\, A_{xs}}\, \delta\hat{\bar{q}}''_{sb,k} \qquad \text{(B-27)}$$

Linearizing and Laplace transforming Eq. (B-1) yields,

$$\frac{\partial\delta\langle\hat{j}\rangle_k}{\partial z} = v_{fg}\,\delta\hat{\Gamma}_k + \Gamma_{k,o}\frac{dv_{fg}}{dp}\,\delta\hat{p} - \frac{\langle\alpha_o\rangle_k}{\rho_g}\,s\,\frac{d\rho_g}{dp}\,\delta\hat{p} \tag{B-28}$$

Rewriting Eq. (B-28) in terms of ξ-coordinates and integrating yields,

$$\delta\langle\hat{j}\rangle_k = \delta\langle\hat{j}\rangle_k^{IN} + \frac{(C_{K,o})_k^{IN}}{C_{o,k,o}\,\bar{\Omega}_{o,k}}(\xi_k - 1)\,\delta\hat{\bar{\Omega}}_{q,k} + [A_1(\xi_k - 1) + B_1 \ln \xi_k]\,\delta\hat{p} \tag{B-29}$$

where,

$$A_1 = \frac{(C_{K,o})_k^{IN}}{C_{o,k,o}\,\bar{\Omega}_{o,k}}\left[v_{fg}\,\gamma_{sb,3} + \Gamma_{k,o}\frac{dv_{fg}}{dp} + \frac{\rho_f}{C_{o,k,o}\,\Delta\rho}\left(v_{fg}\,\gamma_2 - \frac{s}{\rho_g}\frac{d\rho_g}{dp}\right)\right] \tag{B-30}$$

$$B_1 = \frac{(C_{K,o})_k^{IN}}{C_{o,k,o}\,\bar{\Omega}_{o,k}}\left(\langle\alpha_o\rangle_k^{IN} - \frac{\rho_f}{C_{o,k,o}\,\Delta\rho}\right)\left(v_{fg}\,\gamma_2 - \frac{s}{\rho_g}\frac{d\rho_g}{dp}\right)] \tag{B-31}$$

Linearizing and Laplace transforming Eq. (B-2), we obtain,

$$\begin{aligned} s\,\delta\langle\hat{\alpha}\rangle_k + \delta(\hat{C}_K)_k\frac{d\langle\alpha_o\rangle_k}{dz} + (C_{K,o})_k\frac{\partial\delta\langle\hat{\alpha}\rangle_k}{\partial z} &= \frac{1}{\rho_g}\,\delta\hat{\Gamma}_k - \frac{\Gamma_{ko}}{\rho_g^2}\frac{d\rho_g}{dp}\,\delta\hat{p} \\ &\quad - \frac{\langle\alpha_o\rangle_k}{\rho_g}\,s\,\frac{d\rho_g}{dp}\,\delta\hat{p} - \langle\alpha_o\rangle_k\,C_{o,k,o}\frac{\partial\delta\langle\hat{j}\rangle}{\partial z} - C_{o,k,o}\frac{d\langle j_o\rangle_k}{dz}\,\delta\langle\hat{\alpha}\rangle_k \\ &\quad - \langle\alpha_o\rangle_k\frac{d\langle j_o\rangle_k}{dz}\frac{dC_{o,k}}{dp}\,\delta\hat{p} \end{aligned} \tag{B-32}$$

From Eqs. (B-5), (B-12) and (B-29) we have,

$$\delta(\hat{C}_K)_k = C_{o,k,o}\,\delta\langle\hat{j}\rangle_k + \left(\langle j_o\rangle_k\frac{dC_{o,k}}{dp} + \frac{dV_{gj}}{dp}\right)\delta\hat{p} \tag{B-33}$$

$$\frac{d\langle\alpha_o\rangle_k}{dz} = \frac{d\xi_k}{dz}\frac{d\langle\alpha_o\rangle_k}{d\xi_k} = \frac{C_{o,k,o}\,\bar{\Omega}_{k,o}}{(C_{K,o})_k^{IN}}\left(\frac{\rho_f}{C_{o,k,o}\,\Delta\rho} - \langle\alpha_o\rangle_k^{IN}\right)\xi_k^{-2} \tag{B-34}$$

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$$\frac{\partial \delta \langle \hat{j} \rangle_k}{\partial z} = \delta \hat{\bar{\Omega}}_{q,k} + (A_1 + B_1 \xi_k^{-1}) \frac{C_{o,k,o} \bar{\Omega}_{k,o}}{(C_{K,o})_k^{IN}} \delta \hat{p} \qquad \text{(B-35)}$$

Using Eqs. (B-29) and (B-33)-(B-35), Eq. (B-32) becomes,

$$\xi_k \frac{\partial \delta \langle \hat{\alpha} \rangle_k}{\partial \xi_k} + A_2 \, \delta \langle \hat{\alpha} \rangle_k = a_1(\xi_k) \, \delta \hat{\bar{\Omega}}_{q,k} + a_2(\xi_k) \, \delta \langle \hat{j} \rangle_k^{IN} + a_3(\xi_k) \, \delta \hat{p} \qquad \text{(B-36)}$$

where,

$$A_2 \triangleq \frac{s + C_{o,k,o} \bar{\Omega}_{k,o}}{C_{o,k,o} \bar{\Omega}_{k,o}} \qquad \text{(B-37)}$$

$$a_1(\xi_k) \triangleq \frac{1}{C_{o,k,o} \bar{\Omega}_{k,o}} \left[\frac{1}{\rho_g} v_{fg} - \langle \alpha_o \rangle_k C_{o,k,o} - C_{o,k,o} \left(\frac{\rho_f}{C_{o,k,o} \Delta\rho} - \right. \right.$$

$$\left. \left. \langle \alpha_o \rangle_k^{IN} \right) (\xi_k^{-1} - \xi_k^{-2}) \right] \qquad \text{(B-38)}$$

$$a_2(\xi_k) \triangleq - \xi_k^{-2} \frac{C_{o,k,o}}{(C_{K,o})_k^{IN}} \left(\frac{\rho_f}{C_{o,k,o} \Delta\rho} - \langle \alpha_o \rangle_k^{IN} \right) \qquad \text{(B-39)}$$

$$a_3(\xi_k) \triangleq \frac{1}{C_{o,k,o} \bar{\Omega}_{k,o}} \left\{ \frac{1}{\rho_g} (\gamma_{3,sb} + \gamma_2 \langle \alpha_o \rangle_k) - \frac{\Gamma_{k,o}}{\rho_g^2} \frac{d\rho_g}{dp} \right.$$

$$+ \bar{\Omega}_{k,o} \, a_2(\xi_k) \left[C_{o,k,o} (A_1 (\xi_k - 1) + B_1 \ln \xi_k) + \langle j_o \rangle_k \frac{dC_{o,k}}{dp} + \frac{dV_{gj}}{dp} \right]$$

$$\left. - \langle \alpha_o \rangle_k \left[\frac{s}{\rho_g} \frac{d\rho_g}{dp} + \frac{C_{o,k,o}^2 \bar{\Omega}_{k,o}}{(C_{K,o})_k^{IN}} (A_1 + B_1 \xi_k^{-1}) - \bar{\Omega}_{k,o} \frac{dC_{o,k}}{dp} \right] \right\} \qquad \text{(B-40)}$$

Integrating Eq. (B-36) with the boundary condition, $\delta \langle \hat{\alpha}_k (\xi_k = 1) \rangle = \delta \langle \hat{\alpha} \rangle_k^{IN}$, we obtain,

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$$\delta\langle\hat{\alpha}\rangle_k = \delta\langle\hat{\alpha}\rangle_k^{IN}\, \xi_k^{-A_2} + \delta\hat{p}\, \{\frac{B_2}{A_2}(1 - \xi_k^{-A_2}) + \frac{C_2}{A_2 - 1}(\xi_k^{-1} - \xi_k^{-A_2}) + \frac{D_2}{A_2 - 2}$$

$$(\xi_k^{-2} - \xi_k^{-A_2}) + \frac{E_2}{A_2 - 2}[\xi_k^{-2}(\ln \xi_k - \frac{1}{A_2 - 2}) + \frac{1}{A_2 - 2}\xi_k^{-A_2}]\}$$

$$+ \frac{P_{1,k}}{C_{o,k,o}\,\overline{\Omega}_{o,k}\,(C_{K,o})_k^{IN}} \cdot \frac{1}{A_2 - 2}(\xi_k^{-2} - \xi_k^{-A_2})\, \delta\hat{\overline{\Omega}}_{q,k} - \frac{P_{1,k}}{(C_{K,o})_k^{IN,2}}$$

$$\cdot \frac{1}{A_2 - 2}(\xi_k^{-2} - \xi_k^{-A_2})\, \delta\langle\hat{j}\rangle_k^{IN} \qquad \text{(B-41)}$$

where,

$$B_2 \triangleq \frac{1}{C_{o,k,o}\,\overline{\Omega}_{o,k}}[\frac{\Upsilon_{3,Sb}}{\rho_g} - \frac{\Omega_{k,o}}{\rho_g^2\, v_{fg}}\frac{d\rho_g}{dp} + \frac{\rho_f}{C_{o,k,o}\,\Delta\rho}(\frac{\Upsilon_2}{\rho_g} - \frac{s}{\rho_g}\frac{d\rho_g}{dp} - \frac{C_{o,k,o}^2\,\Omega_{k,o}}{(C_{K,o})_k^{IN}}A_1$$

$$- \overline{\Omega}_{k,o}\frac{dC_{o,k}}{dp})] \qquad \text{(B-42)}$$

$$C_2 \triangleq \frac{1}{C_{o,k,o}\,\Omega_{o,k}}[\frac{P_{1,k}}{C_{o,k,o}\,(C_{K,o})_k^{IN}}(\frac{s}{\rho_g}\frac{d\rho_g}{dp} - \frac{\Upsilon_2}{\rho_g}) - \frac{\rho_f\, B_1\, C_{o,k,o}\,\overline{\Omega}_{o,k}}{\Delta\rho\,(C_{K,o})_k^{IN}}] \qquad \text{(B-43)}$$

$$D_2 = \frac{P_{1,k}}{C_{o,k,o}\,(C_{K,o})_k^{IN}}[C_{o,k,o}(A_1 + B_1) - \frac{dV_{gj,k}}{dp} + \frac{V_{gj,k}}{C_{o,k,o}}\frac{dC_{o,k}}{dp}] \qquad \text{(B-44)}$$

$$E_2 \triangleq - \frac{P_{1,k}\, B_1}{(C_{K,o})_k^{IN,2}} \qquad \text{(B-45)}$$

$$P_{1,k} \triangleq (C_{K,o})_k^{IN}(\frac{\rho_f}{\Delta\rho} - C_{o,k,o}\,\langle\alpha_o\rangle_k^{IN}) \qquad \text{(B-46)}$$

By perturbing and Laplacing Eq. (B-22), and using Eq. (B-27), we obtain,

$$\delta\hat{\bar{\alpha}}_{q,k} = E_k^+ \, \delta\hat{h}_{\ell d} + F_k^+ \, \delta\hat{\bar{h}}_{\ell,k} + Q_k^+ \, \delta\hat{q}_k'' - G_k^+ \, \delta\langle\hat{\bar{\alpha}}\rangle_k + V_k^+ \, \delta\hat{p} \qquad \text{(B-47)}$$

where,

$$Q_k \triangleq \frac{\Delta\rho \, P_H \, q_{k,o}''}{A_{xs} \, \rho_f (h_f - h_{\ell d,o})} \qquad \text{(B-48)}$$

$$D_k \triangleq \frac{\bar{h}_{\ell,k,o} - h_{\ell d,o}}{\rho_g \, h_{fg} + \rho_f (h_f - \bar{h}_{\ell,k,o})} \qquad \text{(B-49)}$$

$$E_k^+ \triangleq Q_k \, D_k \, \frac{\bar{h}_{\ell,k,o} - h_f}{(h_f - h_{\ell d,o}) \, (\bar{h}_{\ell,k,o} - h_{\ell d,o})} \qquad \text{(B-50)}$$

$$F_k^+ \triangleq Q_k \, \frac{\rho_g \, h_{fg} + \rho_f (h_f - h_{\ell d,o})}{\{\rho_g \, h_{fg} + \rho_f (h_f - \bar{h}_{\ell,k,o})\}^2} + \frac{H_o}{C_{pf}} \langle\bar{\alpha}_o\rangle_k \qquad \text{(B-51)}$$

$$Q_k^+ \triangleq \frac{Q_k \, D_k}{q_{k,o}''} \qquad \text{(B-52)}$$

$$G_k^+ \triangleq \frac{H_o}{C_{pf}} (h_f - \bar{h}_{\ell,k,o}) \qquad \text{(B-53)}$$

$$\begin{aligned} V_k^+ \triangleq & - \frac{Q_k \, D_k}{\rho_g \, h_{fg} + \rho_f (h_f - \bar{h}_{\ell,k,o})} \left(\rho_g \frac{dh_{fg}}{dp} + h_{fg} \frac{d\rho_g}{dp} + \rho_f \frac{dh_f}{dp}\right) \\ & + Q_k \, D_k \left(\frac{1}{h_{fg}} \frac{dh_{fg}}{dp} + \frac{1}{\rho_g} \frac{d\rho_g}{dp} - \frac{1}{h_f - h_{\ell d}} \frac{dh_f}{dp}\right) - \frac{H_o \langle\alpha_o\rangle_k}{C_{pf}} \frac{dh_f}{dp} - \\ & - \frac{H_o \langle\bar{\alpha}_o\rangle_k}{C_{pf}} (h_f - \bar{h}_{\ell,k,o}) \left(\frac{1}{h_{fg}} \frac{dh_{fg}}{dp} - \frac{1}{v_{fg}} \frac{dv_{fg}}{dp}\right) \end{aligned} \qquad \text{(B-54)}$$

As shown in Appendix-D, the enthalpy perturbation at the void departure point, $\delta\hat{h}_{\ell d}$, is given by,

$$\delta\hat{h}_{\ell d} = H_{d,1}\ \delta\hat{j}_{in} + H_{d,2} \sum_{K=1}^{D} H'_{2,k}\ \delta\hat{q}'''_{k} + H_{d,3}\ \delta\hat{h}_{in} + H_{d,4}\ \delta\hat{p} \qquad (B\text{-}55)$$

The transient analysis of the subcooled boiling liquid enthalpy is given in Appendix-C. In particular, it is found that,

$$\delta\hat{h}_{\ell,k} = W_{1,k}\ \delta\hat{h}^{IN}_{\ell,k} + W_{2,k}\ \delta\hat{q}''_{k} + W_{3,k}\ \delta\langle\hat{\bar{j}}\rangle_{k} + W_{4,k}\ \delta\hat{h}_{\ell d} + W_{5,k}\ \delta\langle\hat{\bar{\alpha}}\rangle_{k} + W_{6,k}\ \delta p \qquad (B\text{-}56)$$

$$\delta\hat{\bar{h}}_{\ell,k} = U_{1,k}\ \delta\hat{h}^{IN}_{\ell,k} + U_{2,k}\ \delta\hat{q}''_{k} + U_{3,k}\ \delta\langle\hat{\bar{j}}\rangle_{k} + U_{4,k}\ \delta\hat{h}_{\ell d} + U_{5,k}\ \delta\langle\hat{\bar{\alpha}}\rangle_{k} + U_{6,k}\ \delta\hat{p} \qquad (B\text{-}57)$$

where $W_{i,k}$ and $U_{i,k}$ are given by Eqs. (C-17)-(C-22) and Eqs. (C-27)-(C-32), respectively.

The node-average values for $\delta\langle\hat{j}\rangle_k$ and $\delta\langle\hat{\alpha}\rangle_k$, obtained from Eqs. (B-29) and (B-41), are,

$$\delta\langle\hat{\bar{j}}\rangle_{k} = \lambda_{1,k}\ \delta\langle\hat{j}\rangle^{IN}_{k} + \lambda_{2,k}\ \delta\hat{\bar{\Omega}}_{q,k} + \lambda_{4,k}\ \delta\hat{p} \qquad (B\text{-}58)$$

$$\delta\langle\hat{\bar{\alpha}}\rangle_{k} = \psi_{1,k}\ \delta\langle\hat{j}\rangle^{IN}_{k} + \psi_{2,k}\ \delta\hat{\bar{\Omega}}_{q,k} + \psi_{3,k}\ \delta\langle\hat{\alpha}\rangle^{IN}_{k} + \psi_{4,k}\ \delta\hat{p} \qquad (B\text{-}59)$$

where,

$$\lambda_{1,k} \triangleq 1 \qquad (B\text{-}60)$$

$$\lambda_{2,k} \triangleq \Delta z_k/2 \qquad (B\text{-}61)$$

$$\lambda_{4,k} \triangleq \frac{(C_{K,o})^{IN}_{k}}{\Delta z_k\ C_{o,k,o}\ \bar{\Omega}_{k,o}} \{(\xi_k - 1)^2\ A_{1s}/2 + B_{1s}\ [\xi_k(\ln\ \xi_k - 1) + 1]\} \qquad (B\text{-}62)$$

$$\psi_{1,k} \triangleq \frac{P_{2,k}(C_{K,o})^{IN}_{k}}{\Delta z_k} \{(\xi_k^{OUT-1}) - 1 - \frac{C_o\ \bar{\Omega}_{o,k}}{s} [(\xi_k^{OUT})^{-\frac{s}{C_o\ \bar{\Omega}_{o,k}}} - 1]\} \qquad (B\text{-}63)$$

$$\psi_{2,k} \triangleq \frac{P_{2,k}(C_{K,o})^{IN,2}_{k}}{\Delta z_k s} \{(\xi_k^{OUT})^{-\frac{s}{C_o\ \bar{\Omega}_{o,k}}} - 1\} - \frac{P_{2,k}(C_{K,o})^{IN,2}_{k}}{\Delta z_k\ C_o\ \bar{\Omega}_{o,k}} [(\xi_k^{OUT-1}) - 1] \qquad (B\text{-}64)$$

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$$\psi_{3,k} \triangleq - \frac{(C_{k,o})_k^{IN}}{\Delta z_k \; s} \{(\xi_k^{OUT})^{-\frac{s}{C_o \, \bar{\Omega}_{o,k}}} - 1\} \tag{B-65}$$

Note that,

$$\begin{aligned} \psi_{4,k} \triangleq \frac{(C_{k,o})_k^{IN}}{C_{o,k,o} \, \bar{\Omega}_{k,o} \, \Delta z_k} \{ & \frac{B_2}{A_2}[(\xi_k^{OUT} - 1) - \frac{1}{1 - A_2}(\xi_k^{OUT^{1-A_2}} - 1)] \\ & + \frac{C_2}{A_2 - 1}[\ell n \; \xi_k^{OUT} - \frac{1}{1 - A_2}(\xi_k^{OUT^{1-A_2}} - 1)] + \frac{D_2}{A_2 - 2} [1 - \xi_k^{OUT^{-1}} \\ & - \frac{1}{1 - A_2}(\xi_k^{OUT^{1-A_2}} - 1)] + \frac{E_2}{A_2 - 2}[\frac{1}{(A_2 - 2) \; (1 - A_2)}(\xi_k^{OUT^{1-A_2}} - 1) \\ & + \frac{1}{A_2 - 2} (\xi_k^{OUT^{-1}} - 1) - \xi_k^{OUT^{-1}}(\ell n \; \xi_k^{OUT} + 1) + 1]\} \end{aligned} \tag{B-66}$$

Substituting Eqs. (B-55), (B-57) and (B-59) into Eq. (B-47) yields,

$$\begin{aligned} \delta\hat{\bar{\Omega}}_{q,k} = {} & Y_{1,k} \; \delta\hat{j}_{in} + Y_{2,k} \; \delta\hat{q}_k'' + Y_{3,k} \; \delta\hat{h}_{\ell,k}^{IN} + Y_{4,k} \; \delta\langle\hat{j}\rangle_k^{IN} + Y_{5,k} \; \delta\langle\hat{\alpha}\rangle_K^{IN} \\ & + Y_{6,k} \sum_{\ell=1}^{D-1} H_{2,\ell}' \; \delta\hat{q}_\ell''' + Y_{7,k} \; \delta\hat{p} + Y_{8,k} \; \delta\hat{h}_{in} + Y_{9,k} \; \delta\hat{h}_{\ell d} \end{aligned} \tag{B-67}$$

where,

$$G_k' \triangleq G_k^+ - F_k^+ \, U_{5,k} \tag{B-68}$$

$$Y_{o,k} \triangleq 1 + G_k' \, \psi_{2,k} - F_k^+ \, U_{3,k} \, \lambda_{2,k} \tag{B-69}$$

$$Y_{1,k} \triangleq (E_k^+ \, H_{d,1} + F_k^+ \, U_{3,k} \, \lambda_{1,k})/Y_{o,k} \tag{B-70}$$

$$Y_{2,k} \triangleq (F_k^+ \, U_{2,k} + Q_k^+)/Y_{o,k} \tag{B-71}$$

$$Y_{3,k} \triangleq F_k^+ \, U_{1,k}/Y_{o,k} \tag{B-72}$$

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$$Y_{4,k} \triangleq (F_k^+ U_{3,k} \lambda_{1,k} - G_k' \psi_{1,k})/Y_{o,k} \tag{B-73}$$

$$Y_{5,k} \triangleq - G_k' \psi_{3,k}/Y_{o,k} \tag{B-74}$$

$$Y_{6,k} \triangleq E_k^+ H_{d,2}/Y_{o,k} \tag{B-75}$$

$$Y_{7,k} \triangleq [E_k^+ H_{d,4} + F_k^+(U_{6,k} + U_{3,k} \lambda_{4,k}) - G_k' \psi_{4,k} + V_k^+]/Y_{o,k} \tag{B-76}$$

$$Y_{8,k} \triangleq E_k^+ H_{d,3}/Y_{o,k} \tag{B-77}$$

$$Y_{9,k} \triangleq U_{4,k} F_k^+/Y_{o,k} \tag{B-78}$$

Using Eqs. (B-56), the boundary condition of $\delta\hat{h}_{\ell,k}$ for the kth node, $\delta\hat{h}^{IN}_{\ell,k}$, can be obtained as,

$$\delta\hat{h}^{IN}_{\ell,k} = \theta_{1,k}\, \delta\hat{h}_{\ell d} + \sum_{i=D}^{k-1} \theta^i_{2,k}\, \delta\hat{q}''_i + \sum_{i=D}^{k-1} \theta^i_{3,k}\, \delta\langle\hat{j}\rangle^{IN}_i + \sum_{i=D}^{k-1} \theta^i_{4,k}\, \delta\hat{h}_{\ell d}$$
$$+ \sum_{i=D}^{k-1} \theta^i_{5,k}\, \delta\langle\hat{\alpha}\rangle^{IN}_i + \sum_{i=D}^{k-1} \theta^i_{6,k}\, \delta\hat{p} \quad \text{, for } k > D \tag{B-79}$$

where,

$$\theta_{1,k} \triangleq \prod_{i=D}^{k-1} W^{OUT}_{1,i} \tag{B-80}$$

$$\theta^i_{\ell,k}\ (\ell = 2,3,4,5,6) \triangleq \begin{cases} \prod_{j=i+1}^{k-1} W^{OUT}_{1,j}\, W^{OUT}_{\ell,i} & \text{, for } k-1 > i > D \\ W_{\ell,i} & \text{, for } i = k-1 \end{cases} \tag{B-81}$$

Inserting Eq. (B-79) into Eq. (B-67) yields,

$$\delta\hat{\bar{\Omega}}_{q,k} = X_{1,k}\,\delta\hat{j}_{in} + X_{2,k}\,\delta\hat{h}_{\ell d} + \sum_{i=D}^{k} X^{i}_{3,k}\,\delta\hat{q}''_{i} + \sum_{i=D}^{k} X^{i}_{4,k}\,\delta\langle\hat{j}\rangle^{IN}_{k} + \sum_{i=D}^{k-1} X^{i}_{5,k}\,\delta\hat{\bar{\Omega}}_{i}$$

$$+ \sum_{i=D}^{k} X^{i}_{6,k}\,\delta\langle\hat{\alpha}\rangle^{IN}_{i} + \sum_{i=D}^{k} X^{i}_{7,k}\,\delta\hat{p} + X_{7,k}\sum_{i=1}^{D-1} H'_{2,i}\,\delta\hat{q}'''_{i} + X_{8,k}\,\delta\hat{h}_{in}$$

$$+ X_{9,k}\,\delta\hat{h}_{\ell d} \qquad \text{(B-82)}$$

where,

$$X_{1,k} \overset{\Delta}{=} Y_{1,k} \qquad \text{(B-83)}$$

$$X_{2,k} \overset{\Delta}{=} Y_{9,k} + Y_{3,k}\sum_{i=D}^{k-1} \theta^{i}_{4,k} \qquad \text{(B-84)}$$

$$X^{i}_{j,k} \overset{\Delta}{=} Y_{3,k}\,\theta^{i}_{j-1,k} \quad \text{, for } j=3,4,6,7 \qquad i < k-1 \qquad \text{(B-85)}$$

$$X^{i}_{5,k} = 0 \qquad \text{(B-86)}$$

$$X^{k}_{3,k} \overset{\Delta}{=} Y_{2,k} \qquad \text{(B-87)}$$

$$X^{k}_{4,k} \overset{\Delta}{=} Y_{4,k} \qquad \text{(B-88)}$$

$$X^{k}_{6,k} \overset{\Delta}{=} Y_{5,k} \qquad \text{(B-89)}$$

$$X^{k}_{7,k} \overset{\Delta}{=} Y_{7,k} \qquad \text{(B-90)}$$

$$X_{7,k} \overset{\Delta}{=} Y_{6,k} \qquad \text{(B-91)}$$

$$X_{8,k} \overset{\Delta}{=} Y_{8,k} \qquad \text{(B-92)}$$

$$X_{9,k} \overset{\Delta}{=} Y_{3,k}\,\theta_{1,k} \qquad \text{(B-93)}$$

Using Eqs. (D-30) and (D-36), Eq. (B-82) can be rewritten as,

$$\delta\hat{\bar{\Omega}}_{q,k} = Z_{1,k}\ \delta\hat{j}_{in} + \sum_{i=D}^{k} Z^{i}_{2,k}\ \delta\hat{q}^{\prime\prime}_{i} + \sum_{i=D+1}^{k} Z^{i}_{3,k}\ \delta\langle\hat{j}\rangle^{IN}_{i} + \sum_{i=D}^{k-1} Z^{i}{}_{4,k}\delta\hat{\bar{\Omega}}_{i}$$

$$+ \sum_{i=D+1}^{k} Z^{i}_{5,k}\ \delta\langle\hat{\alpha}\rangle^{IN}_{i} + Z_{6,k}\ \delta\hat{Z}_{d} + Z_{7,k}\ \delta\hat{h}_{\ell d} + \sum_{i=D}^{k} Z^{i}_{7,k}\ \delta\hat{p}$$

$$+ Z_{8,k} \sum_{i=1}^{D-1} H^{\prime}_{2,i}\ \delta\hat{q}^{\prime\prime\prime}_{i} + Z_{9,k}\ \delta\hat{h}_{in} + Z_{10,k}\ \delta\hat{h}_{\ell d} \qquad \text{(B-94)}$$

where,

$$Z_{1,k} \triangleq X_{1,k} + X^{D}_{4,k} \qquad \text{(B-95)}$$

$$Z^{i}_{j,k} \triangleq X^{i}_{j+1,k} \quad \text{for } j=2,3,4,5 \qquad \text{(B-96)}$$

$$Z_{6,k} \triangleq -\bar{\Omega}_{D,o}\ X^{D}_{4,k} + \theta\ X^{D}_{6,k} \qquad \text{(B-97)}$$

$$Z_{7,k} \triangleq X_{2,k} \qquad \text{(B-98)}$$

$$Z^{i}_{7,k} \triangleq X^{i}_{7,k} \qquad \text{(B-99)}$$

$$Z_{8,k} \triangleq X_{7,k} \qquad \text{(B-100)}$$

$$Z_{9,k} \triangleq X_{8,k} \qquad \text{(B-101)}$$

$$Z_{10,k} \triangleq X_{9,k} \qquad \text{(B-102)}$$

The expressions for $\delta\langle\hat{j}\rangle^{IN}_{k}$ and $\delta\langle\hat{\alpha}\rangle^{IN}_{k}$ can be obtained from Eqs. (D-30), (D-36), (B-29) and (B-41).

$$\delta\langle\hat{j}\rangle^{IN}_{k} = \delta\hat{j}_{in} - \bar{\Omega}_{D,o}\ \delta\hat{z}_{d} + \sum_{i=D}^{k-1} \Delta z_{i}\ \delta\hat{\bar{\Omega}}_{q,i} + \sum_{i=D}^{k-1} PP_{i}\ \delta\hat{p} \qquad \text{(B-103)}$$

and,

$$\delta\langle\hat{\alpha}\rangle_k^{IN} = X_{1,k}\,\delta\hat{j}_{in} + \sum_{i=0}^{k-1} X_{2,k}^{i}\,\delta\hat{\bar{\Omega}}_{q,i} + X_{3,k}\,\delta\hat{Z}_d + X_{4,k}\,\delta\hat{p} \qquad \text{(B-104)}$$

where,

$$PP_i \triangleq A_1(\xi_i - 1) + B_{1,i}\,\ell n\,\xi_i \qquad \text{(B-105)}$$

$$X_{1,k} \triangleq \sum_{i=0}^{k-1} a_i \qquad \text{(B-106)}$$

$$X_{2,k}^{i} \triangleq b_i + \Big(\sum_{j=i+1}^{k} a_j\Big)\cdot\Delta Z_i \qquad \text{(B-107)}$$

$$X_{3,k} \triangleq -\bar{\Omega}_{0,o}\sum_{i=0}^{k-1} a_i + C_k\,\theta \qquad \text{(B-108)}$$

$$X_{4,k} \triangleq \sum_{i=0}^{k-1}\Big(a_i \sum_{j=0}^{i-1} PP_j + d_i\Big) \qquad \text{(B-109)}$$

$$a_i \triangleq \begin{cases} \prod_{j=1}^{k-1-i} \theta_3^{(k-j)}\,\theta_1^{(i)} & \text{, if } i < k-1 \\ \theta_1^{(k-1)} & \text{, if } i = k-1 \end{cases} \qquad \text{(B-110)}$$

$$b_i \triangleq \begin{cases} \prod_{j=1}^{k-1-i} \theta_3^{(k-j)}\,\theta_2^{(i)} & \text{, if } i < k-1 \\ \theta_2^{(k-1)} & \text{, if } i = k-1 \end{cases} \qquad \text{(B-111)}$$

$$C_k \triangleq \prod_{i=0}^{k-1} \theta_3^{(i)} \qquad \text{(B-112)}$$

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$$d_i \triangleq \begin{cases} \prod_{j=1}^{k-1-i} \theta_3^{(k-j)}\, \theta_4^{(i)} & , \text{ if } i < k-1 \\ \theta_4^{(k-1)} & , \text{ if } i=k-1 \end{cases} \tag{B-113}$$

$$\theta_1^{(i)} \triangleq -\, P_{2,i}\; C_{o,i,o}\; \bar{\Omega}_{i,o}(\xi_i^{-2} - \xi_i^{-A_2}) \tag{B-114}$$

$$\theta_2^{(i)} \triangleq P_{2,i}\; (C_{K,o})_i^{IN}\; (\xi_i^{-2} - \xi_i^{-A_2}) \tag{B-115}$$

$$\theta_3^{(i)} \triangleq \xi_i^{-A_2} \tag{B-116}$$

$$\theta_4^{(i)} \triangleq P_{3,i}(1 - \xi_i^{-A_2}) + P_{4,i}(\xi_i^{-1} - \xi_i^{-A_2}) + P_{5,i}(\xi_i^{-2} - \xi^{-A_2}) + P_{6,i}\left[\xi_i^{-2}\left(\ell n\; \xi_i - \frac{1}{A_2 - 2}\right) + \frac{\xi_i^{-A_2}}{A_2 - 2}\right] \tag{B-117}$$

$$P_{2,i} \triangleq \frac{P_{1,i}}{C_{o,i,o}\; \bar{\Omega}_{i,o}(C_{K,o})_i^{IN,2}\; (A_2 - 2)} \tag{B-118}$$

$$P_{3,i} \triangleq \frac{B_2}{A_2} \tag{B-119}$$

$$P_{4,i} \triangleq \frac{C_2}{A_2 - 1} \tag{B-120}$$

$$P_{5,i} \triangleq \frac{D_2}{A_2 - 2} \tag{B-121}$$

$$P_{6,i} \triangleq \frac{E_2}{A_2 - 2} \tag{B-122}$$

Substituting Eqs. (B-103) and (B-104) into Eq. (B-94) yields,

$$\delta\hat{\bar{\Omega}}_{q,k} = T_{1,k}\,\delta\hat{j}_{in} + \sum_{i=D}^{k} T^{i}_{2,k}\,\delta\hat{q}''_{i} + \sum_{i=D}^{k-1} T^{i}_{3,k}\,\delta\hat{\bar{\Omega}}_{q,i} + T_{4,k}\,\delta\hat{Z}_{d} + T_{5,k}\,\delta\hat{h}_{\ell d}$$

$$+ T_{6,k}\,\delta\hat{p} + T_{7,k} \sum_{i=1}^{D-1} H'_{2,i}\,\delta\hat{q}'''_{i} + T_{8,k}\,\delta\hat{h}_{in} + T_{9,k}\,\delta\hat{h}_{\ell d} \qquad \text{(B-123)}$$

where,

$$T_{1,k} \triangleq Z_{1,k} + \sum_{i=D+1}^{k} (Z^{i}_{3,k} + Z^{i}_{5,k}\,X_{1,i}) \qquad \text{(B-124)}$$

$$T_{2,k} \triangleq Z^{i}_{2,k} \qquad \text{(B-125)}$$

$$T^{i}_{3,k} \triangleq Z^{i}_{4,k} + \sum_{j=i+1}^{k} (Z^{j}_{3,k}\,\Delta z_{i} + Z^{j}_{5,k}\,X^{i}_{2,j}) \qquad \text{(B-126)}$$

$$T_{4,k} \triangleq Z_{6,k} + \sum_{i=D+1}^{k} (Z^{i}_{5,k}\,X_{3,i} - \bar{\Omega}_{D,o}\,Z^{i}_{3,k}) \qquad \text{(B-127)}$$

$$T_{5,k} \triangleq Z_{7,k} \qquad \text{(B-128)}$$

$$T_{6,k} \triangleq \sum_{i=D+1}^{k} (Z^{i}_{3,k} \sum_{j=D}^{i-1} PP_{j} + Z^{i}_{5,k}\,X_{4,i}) + \sum_{i=D}^{k} Z^{i}_{7,k} \qquad \text{(B-129)}$$

$$T_{7,k} \triangleq Z_{8,k} \qquad \text{(B-130)}$$

$$T_{8,k} \triangleq Z_{9,k} \qquad \text{(B-131)}$$

$$T_{9,k} \triangleq Z_{10,k} \qquad \text{(B-132)}$$

By forward substitution, we can obtain $\delta\hat{\bar{\Omega}}_{q,k}$ from Eq. (B-123) as,

$$\delta\hat{\bar{\Omega}}_{q,k} = \sum_{i=D+1}^{k} \Lambda_{k,i}\Big[T_{1,i}\ \delta\hat{j}_{in} + \sum_{j=D}^{i} T_{2,i}^{j}\ \delta\hat{q}_{j}'' + T_{3,i}^{D}\ \delta\hat{\bar{\Omega}}_{q,D} + T_{4,i}\ \delta\hat{Z}_{d} + T_{5,i}\ \delta\hat{h}_{\ell d}$$

$$+ T_{6,i}\ \delta\hat{q}_{i}''' + T_{7,i} \sum_{i=1}^{D-1} H_{2,i}'\ \delta\hat{q}_{i}''' + T_{8,i}\ \delta\hat{h}_{in} + T_{9,i}\ \delta\hat{h}_{\ell d} \qquad \text{(B-133)}$$

where,

$$\Lambda_{k,i} = \begin{cases} 1 & \text{, for } i=k \\ \displaystyle\sum_{j_1=i+1}^{k} T_{3,j_1}^{i} \sum_{j_2=j_1+1}^{k} T_{3,j_2}^{j_1} \sum_{j_3=j_2+1}^{k} T_{3,j_3}^{j_2} \sum_{j_m=j_{m-1}+1}^{k} T_{3,j_m}^{j_{m-1}} & \text{, for } m = k-i,\ i \neq k \end{cases} \qquad \text{(B-134)}$$

Note that $\delta\hat{\bar{\Omega}}_{q,D}$ can be obtained from Eq. (B-67). That is,

$$\delta\hat{\bar{\Omega}}_{q,D} = (Y_{1,D} + Y_{4,D})\ \delta\hat{j}_{in} + Y_{2,D}\ \delta\hat{q}_{D}'' + Y_{3,D}\ \delta\hat{h}_{\ell d}$$

$$+ (Y_{5,D}\ \theta - Y_{4,D}\ \bar{\Omega}_{D,o})\ \delta\hat{z}_{d} + Y_{6,D} \sum_{i=1}^{D-1} H_{2,i}'\ \delta\hat{q}_{i}''' + Y_{7,D}\ \delta\hat{p} + Y_{8,D}\ \delta\hat{h}_{in}$$

$$+ Y_{9,D}\ \delta\hat{h}_{\ell d} \qquad \text{(B-135)}$$

Substituting Eq. (B-135) into Eq. (B-133) yields,

$$\delta\hat{\bar{\Omega}}_{q,k} = M_{1,k}'\ \delta\hat{j}_{in} + \sum_{i=D}^{k} (M_{2,k}^{i})'\ \delta\hat{q}_{i}'' + M_{3,k}'\ \delta\hat{Z}_{d} + M_{4,k}'\ \delta\hat{h}_{\ell d} + M_{5,k}'\ \delta\hat{p}$$

$$+ M_{6,k}'\ \delta\hat{h}_{\ell d} + M_{7,k}'\ \delta\hat{h}_{in} + M_{8,k}' \sum_{i=1}^{D-1} H_{2,i}'\ \delta\hat{q}_{i}''' \qquad \text{(B-136)}$$

$$M_{1,k}' \triangleq \sum_{i=D+1}^{k} \Lambda_{k,i}\{T_{1,i} + T_{3,i}^{D}(Y_{1,D} + Y_{4,D})\} \qquad \text{(B-137)}$$

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$$(M^{i}_{2,k})' \triangleq \begin{cases} \sum\limits_{j=D+1}^{k} A_{k,j}(T^{D}_{2,j} + T^{D}_{3,j}\ Y_{2,D}) & \text{, for } i=D \\ \sum\limits_{j=i}^{k} A_{k,j}\ T^{i}_{2,j} & \text{, for } i>D \end{cases} \qquad \text{(B-138)}$$

$$M'_{3,k} \triangleq \sum_{i=D+1}^{k} A_{k,i}\{T^{D}_{3,i}(Y_{5,D}\ \theta - Y_{4,D}\ \bar{\Omega}_{D,o}) + T_{4,i}\} \qquad \text{(B-139)}$$

$$M'_{4,k} \triangleq \sum_{i=D+1}^{k} A_{k,i}\{T^{D}_{3,i}\ Y_{9,D} + T_{5,i}\} \qquad \text{(B-140)}$$

$$M'_{5,k} \triangleq \sum_{i=D+1}^{k} A_{k,i}(T^{D}_{3,i}\ Y_{7,D} + T_{6,i}) \qquad \text{(B-141)}$$

$$M'_{6,k} \triangleq \sum_{i=D+1}^{k} A_{k,i}(T^{D}_{3,i} Y_{3,D} + T_{9,i}) \qquad \text{(B-142)}$$

$$M'_{7,k} \triangleq \sum_{i=D+1}^{k} A_{k,i}\ T_{8,i} \qquad \text{(B-143)}$$

$$M'_{8,k} \triangleq \sum_{i=D+1}^{k} A_{k,i}\ T_{7,i} \qquad \text{(B-144)}$$

Substituting Eqs. (D-13), (D-23), and (A-12) into Eq. (B-136) yields,

$$\delta\hat{\bar{\Omega}}_{q,k} = M_{1,k}\ \delta\hat{j}_{in} + M^{1\phi}_{2,k} \sum_{\ell}^{D-1} H'_{\ell}\ \delta\hat{q}''_{\ell} + \sum_{i=D}^{k} M^{i}_{2,k}\ \delta\hat{q}'''_{i} + M_{3,k}\ \delta\hat{h}_{in} + M_{4,k}\ \delta\hat{p} \qquad \text{(B-145)}$$

where,

$$M_{1,k} \triangleq M'_{1,k} + M_{3,k}\ A_{1} + M'_{4,k}\ H_{d,1} + M'_{6,k}\ H_{d,1} \qquad \text{(B-146)}$$

$$M_{2,k}^{1\phi} \triangleq M_{3,k}' \Lambda_2 \left(1 + \frac{H_{d,2}}{C_p Z_2}\right) + M_{8,k}' - (M_{4,k}' + M_{6,k}') H_{d,2} \frac{H_2}{C_p Z_2} \qquad \text{(B-147)}$$

$$M_{2,k}^{i} \triangleq \begin{cases} (M_{2,k}^{D})' Z_{3,D} + (M_{4,k}' + M_{6,k}') H_{d,2} H_{2,D}' - M_{3,k} M_2 H_{d,2} H_{2,D}'/H_2 & \text{, for } i=D \\ (M_{2,k}^{i})' Z_{3,i} & \text{, for } i>D \end{cases} \qquad \text{(B-148)}$$

$$M_{3,k} \triangleq M_{3,k}' \Lambda_3 + M_{4,k}' H_{d,3} + M_{6,k}' H_{d,3} + M_{7,k}' \qquad \text{(B-149)}$$

$$M_{4,k} \triangleq M_{2,k}' \Lambda_4 + M_{4,k}' H_{d,4} + M_{5,k}' + \sum_{i=D}^{k} (M_{2,k}^{i})' Z_{p,i} + M_{6,k}' H_{d,4} \qquad \text{(B-150)}$$

Substituting Eq. (B-145) into Eqs. (B-103) and (B-104), we obtain,

$$\delta\langle\hat{j}\rangle_k^{IN} = B_{1,k}\, \delta\hat{j}_{in} + B_{2,k}^{1\phi} \sum_{\ell}^{L} H_\ell'\, \delta\hat{q}_\ell''' + \sum_{i=D}^{k-1} B_{2,k}^{i}\, \delta\hat{q}_i''' + B_{3,k}\, \delta\hat{h}_{in} + B_{4,k}\, \delta\hat{p} \qquad \text{(B-151)}$$

and,

$$\delta\langle\hat{\alpha}\rangle_k^{IN} = K_{1,k}\, \delta\hat{j}_{in} + K_{2,k}^{1\phi} \sum_{\ell}^{L} H_\ell'\, \delta\hat{q}_\ell''' + \sum_{i=D}^{k-1} K_{2,k}^{i}\, \delta\hat{q}_i''' + K_{3,k}\, \delta\hat{h}_{in} + K_{4,k}\, \delta\hat{p} \qquad \text{(B-152)}$$

where,

$$B_{1,k} \triangleq 1 - \bar{\Omega}_{D,o} \Lambda_1 + \sum_{i=D}^{k-1} \Delta Z_i M_{1,i} \qquad \text{(B-153)}$$

$$B_{2,k}^{1\phi} \triangleq - \bar{\Omega}_{D,o} \Lambda_2 \left(1 + \frac{H_{d,2}}{C_p Z_2}\right) + \sum_{i=D}^{k-1} \Delta Z_i M_{2,i}^{1\phi} \qquad \text{(B-154)}$$

$$B_{2,k}^{i} \triangleq \begin{cases} - \bar{\Omega}_{D,o} M_4 + \sum_{j=D+1}^{k-1} M_{2,j}^{D} \Delta Z_j & \text{, for } i=D \\ \sum_{j=i}^{k-1} M_{2,j}^{i} \Delta Z_j & \text{, for } i \neq D \end{cases} \qquad \text{(B-155)}$$

$$B_{3,k} \triangleq -\bar{\Omega}_{D,o}\,\Lambda_3 + \sum_{i=D}^{k-1} \Delta z_i\, M_{3,i} \tag{B-156}$$

$$B_{4,k} \triangleq -\bar{\Omega}_{D,o}\,\Lambda_4 + \sum_{i=D}^{k-1} \left(\Delta z_i\, M_{4,i} + PP_i\right) \tag{B-157}$$

$$K_{1,k} \triangleq X_{1,k} + \sum_{i=D}^{k-1} X^{i}_{2,k}\, M_{1,i} + X_{3,k}\,\Lambda_1 \tag{B-158}$$

$$K^{1\phi}_{2,k} \triangleq \sum_{i=D}^{k-1} X^{i}_{2,k}\, M^{1\phi}_{2,i} + X_{3,k}\,\Lambda_2\left(1 + \frac{H_{d,2}}{C_p Z_2}\right) \tag{B-159}$$

$$K^{i}_{2,k} \triangleq \begin{cases} \displaystyle\sum_{j=D+1}^{k-1} M^{D}_{2,j}\, X^{j}_{2,D} + X_{3,k}\, M_4 & \text{, for } i=D \\[2ex] \displaystyle\sum_{j=i}^{k-1} M^{i}_{2,j}\, X^{j}_{2,i} & \text{, for } i\neq D \end{cases} \tag{B-160}$$

$$K_{3,k} \triangleq \sum_{i=D}^{k-1} X^{i}_{2,k}\, M_{3,i} + X_{3,k}\,\Lambda_3 \tag{B-161}$$

$$K_{4,k} \triangleq \sum_{i=D}^{k-1} X^{i}_{2,k}\, M_{4,i} + X_{3,k}\,\Lambda_4 + X_{4,k} \tag{B-162}$$

$$M_4 \triangleq \frac{H_{d,2}\,\rho_f\, A_{xs}\, j_{in,o}}{\rho_H\, q''_{d,o}} \tag{B-163}$$

$$\Lambda_2 \triangleq \frac{H_2\,\rho_f\, A_{xs}\, j_{in,o}}{\rho_H\, q''_{d,o}} \tag{B-164}$$

APPENDIX C

PERTURBATIONS IN LIQUID PHASE ENTHALPY

The liquid phase energy conservation equation can be written as,

$$\rho_\ell(1 - \langle\alpha\rangle_k)\frac{\partial h_{\ell,k}}{\partial t} + \rho_\ell(1 - \langle\alpha\rangle_k)\, u_{\ell,k}\frac{\partial h_{\ell,k}}{\partial z} = \frac{P_H\, q''_k}{A_{xs}} + \frac{1}{J}\frac{\partial p}{\partial t} - \Gamma_k(h_g - h_{\ell,k}) - \rho_g\langle\alpha\rangle_k\frac{dh_g}{dt} \qquad \text{(C-1)}$$

Using drift-flux parameters, we can write,

$$\rho_\ell(1 - \langle\alpha\rangle_k)\, u_{\ell,k} = \rho_\ell[\langle j\rangle_k(1 - C_{0,k,o}\langle\alpha\rangle_k) - V_{gj,k}\langle\alpha\rangle_k] \qquad \text{(C-2)}$$

Linearizing and Laplace transforming Eq. (B-3) yields,

$$\delta\hat{\Gamma}_k = E_k\,\delta\hat{h}_{\ell d} + F_k\,\delta\hat{h}_{\ell,k} + S_k\,\delta\hat{q}''_k + A_k\,\delta\langle\hat{\alpha}\rangle_k + V_k\,\delta\hat{p} \qquad \text{(C-3)}$$

where,

$$Q_k \triangleq \frac{P_H\, q''_{k,o}\,\rho_g}{A_{xs}(h_f - h_{\ell d})} \qquad \text{(C-4)}$$

$$D_k \triangleq \frac{h_{\ell,k,o} - h_{\ell d}}{\rho_g\, h_{fg} + \rho_f(h_f - h_{\ell,k,o})} \qquad \text{(C-5)}$$

$$E_k \triangleq Q_k\, D_k\frac{h_{\ell,k,o} - h_f}{(h_{\ell,k,o} - h_{\ell d,o})\,(h_f - h_{\ell d,o})} \qquad \text{(C-6)}$$

$$F_k \triangleq Q_k\frac{\rho_g\, h_{fg} + \rho_f(h_f - h_{\ell d,o})}{[\rho_g\, h_{fg} + \rho_f(h_f - h_{\ell,k,o})]^2} + \frac{H_o\langle\alpha_o\rangle_k}{v_{fg}\, C_{pf}} \qquad \text{(C-7)}$$

$$S_k \triangleq \frac{Q_k\, D_k}{q''_{k,o}} \qquad \text{(C-8)}$$

$$A_k \triangleq - \frac{H_o(h_f - h_{\ell,k,o})}{v_{fg}\ C_{pf}} \tag{C-9}$$

$$V_k \triangleq - \frac{Q_k\ D_k}{\rho_g\ h_{fg} + \rho_f(h_f - h_{\ell,k,o})} \left(\rho_g \frac{dh_{fg}}{dp} + h_{fg} \frac{d\rho_g}{dp} + \rho_f \frac{dh_f}{dp}\right)$$

$$+ Q_k\ D_k \left(\frac{1}{\rho_g} \frac{d\rho_g}{dp} - \frac{1}{h_f - h_{\ell d,o}} \frac{dh_f}{dp}\right) - \frac{H_o \langle\alpha_o\rangle_k}{v_{fg}\ C_{pf}} \frac{dh_f}{dp}$$

$$+ \frac{H_o \langle\alpha_o\rangle_k}{v_{fg}^2\ C_{pf}}(h_f - h_{\ell,k,o}) \frac{dv_{fg}}{dp} + \frac{s}{h_{fg}}\left[\frac{1}{J} - (1 - \langle\alpha_o\rangle_k)\ \rho_f \frac{dh_f}{dp} - \langle\alpha_o\rangle_k\ \rho_g \frac{dh_g}{dp}\right] \tag{C-10}$$

Linearizing and Laplace transforming Eq. (C-2), we obtain,

$$\delta[\rho_\ell(1 - \langle\hat{\alpha}\rangle_k)\ u_{\ell,k}] = C_1\ \delta\langle\hat{j}\rangle_k + C_2\ \delta\langle\hat{\alpha}\rangle_k + C_3\ \delta\hat{p} \tag{C-11}$$

where,

$$C_1 \triangleq \rho_f(1 - C_{o,k,o}\langle\alpha_o\rangle_k) \tag{C-12}$$

$$C_2 \triangleq - \rho_f(\langle j_o\rangle_k\ C_{o,k,o} + V_{gj,k,o}) \tag{C-13}$$

$$C_3 \triangleq - \rho_f\left[\langle j_o\rangle_k\ \langle\alpha_o\rangle_k \frac{dC_{o,k,o}}{dp} + \langle\alpha_o\rangle_k \frac{dV_{gj,k}}{dp}\right] \tag{C-14}$$

Perturbing and Laplace transforming Eq. (C-1), we obtain,

$$\rho_f(1 - \langle\alpha_o\rangle_k)\ s\delta\hat{h}_{\ell,k} + (C_1\delta\langle\hat{j}\rangle_k + C_2\delta\langle\hat{\alpha}\rangle_k + C_3\delta\hat{p}) \frac{dh_{\ell,k,o}}{dz}$$

$$+ G_{k,o}(1 - \langle\alpha_o\rangle_k) \frac{\partial\delta\hat{h}_{\ell,k}}{\partial z} = \frac{P_H\ \delta\hat{q}_k''}{A_{xs}} + \frac{s}{J}\ \delta\hat{p} - \Gamma_{k,o}\left(\frac{dh_g}{dp}\ \delta\hat{p} - \delta\hat{h}_{\ell,k}\right)$$

$$- (h_g - h_{\ell,k,o})\ \delta\hat{\Gamma}_k - \rho_g\langle\alpha_o\rangle_k\ s \frac{dh_g}{dp}\ \delta\hat{p} \tag{C-15}$$

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To allow the integration for the above equation, we can replace the variables in the coefficients of Eq. (C-15) by their node-averaged values. Then, substituting Eqs. (C-3) into Eq. (C-15), and integrating, yields,

$$\delta\hat{h}_{\ell,k} = W_{1,k}\delta\hat{h}^{IN}_{\ell,k} + W_{2,k}\delta\hat{q}''_k + W_{3,k}\delta\hat{\langle\bar{J}\rangle}_k + W_{4,k}\delta\hat{h}_{\ell d} + W_{5,k}\delta\hat{\langle\bar{\alpha}\rangle}_k + W_{6,k}\delta\hat{p} \tag{C-16}$$

where,

$$W_{1,k} \triangleq e^{-C^*(z-z_k^{IN})} \tag{C-17}$$

$$W_{2,k} \triangleq \left[\frac{P_H}{A_{xs}} - (h_g - \bar{h}_{\ell,k,o})\,\bar{S}_k\right] H_k \tag{C-18}$$

$$W_{3,k} \triangleq -\,C_1\,\frac{\overline{dh}_{\ell,k,o}}{dz}\,H_k \tag{C-19}$$

$$W_{4,k} \triangleq -\,(h_g - \bar{h}_{\ell,k,o})\,\bar{E}_k\,H_k \tag{C-20}$$

$$W_{5,k} \triangleq -\left[(h_g - \bar{h}_{\ell,k,o})\,\bar{A}_k + C_2\,\frac{\overline{dh}_{\ell,k,o}}{dz}\right] H_k \tag{C-21}$$

$$W_{6,k} \triangleq \left[\frac{S}{J} - \Gamma_{k,o}\,\frac{dh_g}{dp} - (h_g - \bar{h}_{\ell,k,o})\,\bar{V}_k - \rho_g\langle\bar{\alpha}_o\rangle_k\,s\,\frac{dh_g}{dp} - C_3\,\frac{\overline{dh}_{\ell,k,o}}{dz}\right] H_k \tag{C-22}$$

$$H_k \triangleq \left[1 - e^{-C^*(z-z_k^{IN})}\right] f \tag{C-23}$$

$$\tau \triangleq 1/\left[s\rho_f(1 - \langle\bar{\alpha}_o\rangle_k) - \Gamma_{k,o} + (h_g - \bar{h}_{\ell,k,o})\,F_k\right] \tag{C-24}$$

$$C^* \triangleq \left[s\rho_f\,(1 - \langle\bar{\alpha}_o\rangle_k) - \Gamma_{k,o} + (h_g - \bar{h}_{\ell,k,o})\,F_k\right]/\left[G_{k,o}(1 - \langle\bar{\alpha}_o\rangle_k)\right] \tag{C-25}$$

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The nodal averaged value of $\delta\hat{h}_{\ell,k}$ can be obtained from Eq. (C-16)

$$\delta\hat{\bar{h}}_{\ell,k} \triangleq \frac{1}{\Delta z_k}\int_{\Delta z_k} \delta\hat{h}_{\ell,k}\,dz = U_{1,k}\delta\hat{h}^{IN}_{\ell,k} + U_{2,k}\delta\hat{q}''_k + U_{3,k}\delta\langle\hat{j}\rangle_k + U_{4,k}\delta\hat{h}_{\ell d}$$

$$+ U_{5,k}\delta\langle\hat{\bar{\alpha}}\rangle_k + U_{6,k}\delta\hat{p} \qquad \text{(C-26)}$$

where,

$$U_{1,k} \triangleq \frac{1}{C^*\Delta z_k}\left(1 - e^{-C^*\Delta z_k}\right) \qquad \text{(C-27)}$$

$$U_{2,k} \triangleq \left[\frac{P_H}{A_{xs}} - (h_g - \bar{h}_{\ell,k,o})\,\bar{S}_k\right] I_k \qquad \text{(C-28)}$$

$$U_{3,k} \triangleq -\,C_1\,\frac{d\bar{h}_{\ell,k,o}}{dz}\,I_k \qquad \text{(C-29)}$$

$$U_{4,k} \triangleq -\,(h_g - \bar{h}_{\ell,k,o})\,\bar{E}_k\,I_k \qquad \text{(C-30)}$$

$$U_{5,k} \triangleq -\left[(h_g - \bar{h}_{\ell,k,o})\,\bar{A}_k + C_2\,\frac{d\bar{h}_{\ell,k,o}}{dz}\right] I_k \qquad \text{(C-31)}$$

$$U_{6,k} \triangleq \left[\frac{s}{J} - \Gamma_{k,o}\,\frac{dh_g}{dp} - (h_g - \bar{h}_{\ell,k,o})\,\bar{V}_k - \rho_g\langle\bar{\alpha}_o\rangle_k\, s\,\frac{dh_g}{dp} - C_3\,\frac{d\bar{h}_{\ell,k,o}}{dz}\right] I_k \qquad \text{(C-32)}$$

$$I_k \triangleq \frac{1}{\Delta z_k}\int_{z_k^{IN}}^{z_k^{OUT}} H_k\,dz = (1 - U_{1,k})\,f \qquad \text{(C-33)}$$

APPENDIX D

PERTURBATIONS IN LIQUID ENTHALPY, VOID FRACTION AND VOLUMETRIC FLUX AT THE VOID DEPARTURE POINT

1. Perturbation in Liquid Enthalpy at the Void Departure Point

Using Saha's model,(3) the liquid enthalpy at the void departure point, denoted as $h_{\ell d}$, is given by,

$$h_{\ell d} = \begin{cases} h_f - 0.0022 \dfrac{q_d'' D_H c_{p\ell}}{\kappa_\ell} & \text{, for Pe} \triangleq \dfrac{G D_H c_{p\ell}}{\kappa_\ell} < 70{,}000 \\ h_f - 154 \dfrac{q_d''}{G_d} & \text{, for Pe} > 70{,}000 \end{cases} \tag{D-1}$$

Hence,

$$\delta\hat{h}_{\ell d} = \begin{cases} \dfrac{dh_f}{dp} \delta\hat{p} - 0.0022 \dfrac{D_H c_{p\ell}}{k_\ell} \delta\hat{q}_d'' & \text{, for Pe} < 70{,}000 \\ \dfrac{dh_f}{dp} \delta\hat{p} - \dfrac{154}{G_o} \delta\hat{q}_d'' + \dfrac{154\, q_{do}''}{G_o^2} \delta\hat{G}_d & \text{, for Pe} > 70{,}000 \end{cases} \tag{D-2}$$

Eq. (D-2) can be rewritten as,

$$\delta\hat{h}_{\ell d} = X_1 \delta\hat{q}_d'' + X_2 \delta\hat{G}_d + X_3 \delta\hat{p} \tag{D-3}$$

where,

$$X_1 \triangleq \begin{cases} -0.0022 \dfrac{D_H c_{p\ell}}{\kappa_\ell} & \text{, Pe} < 70{,}000 \\ -\dfrac{154}{G_o} & \text{, Pe} > 70{,}000 \end{cases} \tag{D-4}$$

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$$X_2 \triangleq \begin{cases} 0 & , Pe < 70{,}000 \\ \dfrac{154\, q''_{d,o}}{G_o^2} & , Pe > 70{,}000 \end{cases} \qquad \text{(D-5)}$$

$$X_3 \triangleq \frac{dh_f}{dp} \text{ , for all } Pe \qquad \text{(D-6)}$$

Using Eq. (A-6) at $z = z_{d,o}$ yields,

$$\delta\hat{q}''_d = Q_1 \delta\hat{j}_{in} + Q_2 \sum_{k=1}^{D} H'_{2,k} \delta\hat{q}'''_k + Q_3 \delta\hat{h}_{in} + Q_4 \delta\hat{p} \qquad \text{(D-7)}$$

where,

$$H'_{2,k} \triangleq \begin{cases} -\dfrac{H_2\, H'_k}{c_p\, Z_2} & , \text{if } k < D-1 \\ 1 & , \text{if } k = D \end{cases} \qquad \text{(D-8)}$$

$$Q_1 \triangleq \frac{q''_{d,o}}{(1 - H_{1\phi}\, Z_1)} \left(\frac{0.8}{j_o} - \frac{H_{1\phi}\, H_1}{c_p\, q''_o} \right) \qquad \text{(D-9)}$$

$$Q_2 \triangleq \frac{H_{1\phi}\, Z_2}{(1 - H_{1\phi}\, Z_1)} \qquad \text{(D-10)}$$

$$Q_3 \triangleq - \frac{H_{1\phi}\, H_3}{(1 - H_{1\phi}\, Z_1)\, c_p} \qquad \text{(D-11)}$$

$$Q_4 \triangleq \frac{H_{1\phi}}{(1 - H_{1\phi}\, Z_1)\, c_p} \left[v_f (1 - \beta_p\, T_\infty) - H_4 \right] \qquad \text{(D-12)}$$

Substituting Eqs. (D-7)-(D-12) into Eq. (D-3) obtains,

$$\delta\hat{h}_{\ell d} = H_{d,1}\,\delta\hat{j}_{in} + H_{d,2}\sum_{k=1}^{D} H'_{2,k}\,\delta\hat{q}_k''' + H_{d,3}\,\delta\hat{h}_{in} + H_{d,4}\,\delta\hat{p} \qquad \text{(D-13)}$$

where,

$$H_{d,1} \triangleq X_1\, Q_2 + X_2\, \rho_f \qquad \text{(D-14)}$$

$$H_{d,2} \triangleq X_1\, Q_2 \qquad \text{(D-15)}$$

$$H_{d,3} \triangleq X_1\, Q_3 \qquad \text{(D-16)}$$

$$H_{d,4} \triangleq X_1\, Q_4 + X_3 \qquad \text{(D-17)}$$

2. Perturbation of the Location of the Void Departure Point

The void departure point, z_d, is implicitly defined as,

$$h(z_d(t)) = h_{\ell d}(t) \qquad \text{(D-18)}$$

Considering small variations around the steady-state values, we have,

$$\delta h_{\ell d} \triangleq h_{\ell d}(z_d) - h_{\ell do}(z_{d,o}) = h_{\ell d}(z_d) - h(z_{d,o}) + h(z_{d,o}) - h_{\ell do}(z_{d,o})$$

$$= \left.\frac{dh_o(z)}{dz}\right|_{z_{d,o}} \delta z_d + \delta h(z_{d,o}) \qquad \text{(D-19)}$$

Eq. (D-19) yields,

$$\delta\hat{z}_d = -\frac{1}{\left.\frac{dh_o}{dz}\right|_{z_{d,o}}}\left(\delta\hat{h}(z_{d,o},s) - \delta\hat{h}_{\ell d}\right) \qquad \text{(D-20)}$$

From Eqs. (2.7) and (2.18), we have,

$$\left.\frac{dh_o}{dz}\right|_{z_{d,o}} = \frac{P_H\, q''_{d,o}}{\rho_f\, A_{xs}\, j_{in,o}} \tag{D-21}$$

$$\delta\hat{h}(z_{d,o},s) = H_1\,\delta\hat{j}_{in} + H_2 \sum_{k=1}^{D-1} H'_k\, \delta\hat{q}'''_k + H_3\, \delta\hat{h}_{in} + H_4\, \delta\hat{p} \tag{D-22}$$

Substituting Eqs. (D-13), (D-21) and (D-22) into Eq. (D-20), we obtain,

$$\delta\hat{Z}_d = \Lambda_1\delta\hat{j}_{in} + \sum_{k=1}^{D} \Lambda_{2,k}\delta\hat{q}'''_k + \Lambda_3\delta\hat{h}_{in} + \Lambda_4\delta\hat{p} \tag{D-23}$$

where,

$$\Lambda_i = -\frac{\rho_f\, A_{xs}\, j_{in,o}}{P_H\, q''_{d,o}}\left(H_i - H_{d,i}\right) \qquad \text{for } i = 1,3,4 \tag{D-24}$$

$$\Lambda_{2,k} \triangleq -\frac{\rho_f\, A_{xs}\, j_{in,o}}{P_H\, q''_{d,o}}\left(H_2\, H'_k - H_{d,2}\, H'_{2,k}\right) \tag{D-25}$$

3. Perturbation in Void Fraction at Void Departure Point

We assume that there is no steam generation for $z < z_d$, that is, we neglect Region-I voids,(3) thus,

$$\langle\alpha(z_d(t))\rangle = 0 \tag{D-26}$$

Expanding Eq. (D-26) yields,

$$\langle\alpha(z_d)\rangle = \langle\alpha_o(z_{d,o})\rangle + \left.\frac{d\langle\alpha_o\rangle}{dz}\right|_{z=z_{d,o}} \delta z_d + \delta\langle\alpha(z_{d,o})\rangle = 0 \tag{D-27}$$

Since, $\langle\alpha(z_d)\rangle = \langle\alpha_o(z_{d,o})\rangle = 0$, Eq. (D-27) yields,

$$\delta\langle\alpha(\hat{z}_{d,o})\rangle = -\left.\frac{d\langle\alpha_o\rangle}{dz}\right|_{z=z_{d,o}} \delta\hat{z}_d \tag{D-28}$$

From Eq. (B-12), we have,

$$\left.\frac{d\langle\alpha_o\rangle}{dz}\right|_{z=z_{d,o}} = \frac{\bar{\Omega}_{D,o}}{\rho_g\, v_{fg}(C_{k,o})_D^{IN}} \tag{D-29}$$

The subscript "D" represents the node with the void departure point at its inlet. Thus,

$$\delta\langle\hat{\alpha}\rangle_D^{IN} = \theta\, \delta\hat{z}_d \tag{D-30}$$

where,

$$\theta \triangleq -\frac{\bar{\Omega}_{D,o}}{\rho_g\, v_{fg}(C_{K,o})_D^{IN}} \tag{D-31}$$

4. Perturbation in Volumetric Flux at the Void Departure Point

Since the volumetric flux at z_d is given as,

$$\langle j(z_d(t))\rangle = j_{in}(t) \tag{D-32}$$

We can expand Eq. (D-32) to obtain,

$$\langle j(z_{d,o})\rangle + \left.\frac{d\langle j_o\rangle}{dZ}\right|_{z=z_{d,o}} \delta z_d + \delta\langle j(z_{d,o})\rangle = j_{in,o} + \delta j_{in} \tag{D-33}$$

Hence,

$$\delta\langle \hat{j}(z_{d,o},s)\rangle = -\left.\frac{d\langle j_o\rangle}{dz}\right|_{z=z_{d,o}} \delta\hat{z}_d + \delta\hat{j}_{in} \tag{D-34}$$

By Eq. (B-9) we obtain,

$$\frac{d\langle j_o\rangle_D}{dz} = \bar{\Omega}_{D,o} \tag{D-35}$$

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Finally, we have,

$$\delta\langle\hat{j}\rangle_D^{IN} = \delta\hat{j}_{in} - \bar{\Omega}_{D,o}\,\delta\hat{z}_d \qquad \text{(D-36)}$$

APPENDIX E

VOLUMETRIC FLUX AND VOID FRACTION PERTURBATIONS IN THE BULK BOILING REGION

The k^{th} node continuity and void propagation equations are,

$$\frac{\partial\langle j\rangle_k}{\partial z} = v_{fg}\,\Gamma_k - \frac{\langle\alpha\rangle_k}{\rho_g}\frac{d\rho_g}{dt} \tag{E-1}$$

and,

$$\frac{\partial\langle\alpha\rangle_k}{\partial t} + (C_K)_k\frac{\partial\langle\alpha\rangle_k}{\partial z} = \frac{\Gamma_k}{\rho_g} - \frac{\langle\alpha\rangle_k}{\rho_g}\frac{d\rho_g}{dt} - \langle\alpha\rangle_k\,C_{o,k}\frac{\partial\langle j\rangle}{\partial z} \tag{E-2}$$

Note that we still assume liquid incompressibility in this region. The vapor generation rate and kinematic wave speed are given by,

$$\Gamma_k = \frac{1}{h_{fg}}\left[\frac{q''_k\,P_H}{A_{xs}} + \frac{1}{J}\frac{dp}{dt} - \rho_f(1 - \langle\alpha\rangle_k)\frac{dh_f}{dt} - \rho_g\langle\alpha\rangle_k\frac{dh_g}{dt}\right] \tag{E-3}$$

and,

$$(C_K)_k = C_{o,k}\langle j\rangle_k + V_{gj,k} \tag{E-4}$$

For steady-state, Eqs. (E-1)-(E-3) reduce to,

$$\frac{d\langle j_o\rangle_k}{dz} = v_{fg,o}\,\Gamma_{k,o} \triangleq \Omega_{k,o} \tag{E-5}$$

$$(C_{K,o})_k\frac{d\langle\alpha_o\rangle_k}{dz} = \frac{\Gamma_{k,o}}{\rho_g} - \langle\alpha_o\rangle_k\,C_{o,k,o}\frac{d\langle j_o\rangle_k}{dz} \tag{E-6}$$

$$\Gamma_{k,o} = \frac{q''_{k,o}\,P_H}{h_{fg}\,A_{xs}} \tag{E-7}$$

Integrating Eq. (E-5) gives,

$$\langle j_o\rangle_k = \langle j_o\rangle_k^{IN} + \Omega_{o,k}\,(z - z_k) \tag{E-8}$$

where z is in node-k (i.e., $z_k < z < z_{k+1}$).

Substituting Eq. (E-8) into Eq. (E-4) yields,

$$(C_{K,o})_k = (C_{K,o})_k^{IN} + C_{o,k,o}\,\Omega_{o,k}(z - z_k) \tag{E-9}$$

Defining a new variable, ξ_k, as follows,

$$\xi_k = \frac{(C_{K,o})_k}{(C_{K,o})_k^{IN}} \tag{E-10}$$

yields,

$$d\xi_k = \frac{C_{o,K,o}\,\Omega_{o,k}}{(C_{K,o})_k^{IN}}\,dz \tag{E-11}$$

and,

$$\xi_k = 1 + \frac{C_{o,K,o}\,\Omega_{o,K}}{(C_{K,o})_k^{IN}}\,(z - z_k) \tag{E-12}$$

Replacing z_k by ξ_k in Eqs. (E-8) and (E-6), respectively, we obtain,

$$\langle j_o\rangle_k = \frac{1}{C_{o,k,o}}\left[(C_{K,o})_k^{IN}\,\xi_k - V_{gj}\right] \tag{E-13}$$

and,

$$\frac{d}{d\xi_k}(\langle\alpha_o\rangle_k\,\xi_k) = \frac{\rho_f}{C_{o,k,o}\,\Delta\rho} \tag{E-14}$$

Eq. (E-14) can be integrated to obtain,

$$\langle\alpha_o\rangle_k = \frac{\rho_f}{C_{o,k,o}\,\Delta\rho} - \xi_k^{-1}\,\frac{P_{1,k}}{C_{o,k,o}(C_{K,o})_k^{IN}} \tag{E-15}$$

where,

$$P_{1,k} \triangleq (C_{K,o})_k^{IN}\left(\frac{\rho_f}{\Delta\rho} - C_{o,k,o}\langle\alpha_o\rangle_k^{IN}\right) \tag{E-16}$$

Perturbing and Laplace transforming Eq. (E-3) yields,

$$\delta\hat{\Gamma}_k = -\frac{q''_{o,k}\ P_H}{h_{fg}^2\ A_{xs}}\frac{dh_{fg}}{dp}\,\delta\hat{p} + \frac{1}{h_{fg}}\Big[\frac{P_H}{A_{xs}}\,\delta\hat{q}''_k + \frac{s}{J}\,\delta\hat{p} - \rho_f(1 - \langle\alpha_o\rangle_k)\ s\,\frac{dh_f}{dp}\,\delta\hat{p}$$

$$- \rho_g\langle\alpha_o\rangle_k\ s\,\frac{dh_g}{dp}\,\delta\hat{p}\Big] \qquad \text{(E-17)}$$

Substituting Eq. (A-12) into Eq. (E-17) and rearranging gets,

$$\delta\hat{\Gamma}_k = \frac{P_H\ Z_3}{h_{fg}\ A_{xs}}\,\delta\hat{q}'''_k + (\gamma_2\langle\alpha_o\rangle_k + \gamma_{3,k})\ \delta\hat{p} \qquad \text{(E-18)}$$

where,

$$\gamma_2 \triangleq \frac{s}{h_{fg}}\Big(\rho_f\,\frac{dh_f}{dp} - \rho_g\,\frac{dh_g}{dp}\Big) \qquad \text{(E-19)}$$

$$\gamma_{3,k} \triangleq \frac{P_H\ Z_p}{h_{fg}\ A_{xs}} - \frac{q''_{o,k}\ P_H}{h_{fg}^2\ A_{xs}}\,\frac{dh_{fg}}{dp} + \frac{s}{h_{fg}}\Big(\frac{1}{J} - \rho_f\,\frac{dh_f}{dp}\Big) \qquad \text{(E-20)}$$

Eq. (E-1) can be integrated and Laplace transformed to obtain,

$$\frac{\partial\delta\langle\hat{j}\rangle_k}{\partial z} = v_{fg}\ \delta\hat{\Gamma}_k + \Gamma_{k,o}\,\frac{dv_{fg}}{dp}\,\delta\hat{p} - \frac{\langle\alpha_o\rangle_k}{\rho_g}\ s\,\frac{d\rho_g}{dp}\,\delta\hat{p} \qquad \text{(E-21)}$$

Substituting Eq. (E-18) into Eq. (E-21) and rearranging yields,

$$\frac{\partial\delta\langle\hat{j}\rangle_k}{\partial z} = \delta\hat{\Omega}_{p,k} + \gamma_{1,k}\ \delta\hat{p} \qquad \text{(E-22)}$$

where,

$$\delta\hat{\Omega}_{p,k} \triangleq \frac{v_{fg}\ P_H\ Z_3}{h_{fg}\ A_{xs}}\,\delta\hat{q}'''_k \qquad \text{(E-23)}$$

$$\gamma_{1,k} \triangleq v_{fg}\ \gamma_2\langle\alpha_o\rangle_k + v_{fg}\ \gamma_3 + \Gamma_k\,\frac{dv_{fg}}{dp} - \frac{\langle\alpha_o\rangle_k}{\rho_g}\ s\,\frac{d\rho_g}{dp} \qquad \text{(E-24)}$$

Using Eqs. (E-12) and (E-13), Eq. (E-22) becomes,

$$\frac{\partial \delta \langle \hat{j} \rangle_k}{\partial \xi_k} = \frac{(C_{K,o})_k^{IN}}{C_{o,k,o}\ \Omega_{o,k}}\ \delta \hat{\Omega}_{p,k} + (A_{1,k} + B_{1,k}\ \xi_k^{-1})\ \delta \hat{p} \tag{E-25}$$

where,

$$A_{1,k} \triangleq \frac{(C_{K,o})_k^{IN}}{C_{o,k,o}\ \Omega_{o,k}} \left[v_{fg}\ \gamma_{3,k} + \Gamma_{k,o} \frac{dv_{fg}}{dp} + \frac{\rho_f}{C_{o,k,o}\ \Delta\rho} \left(v_{fg}\ \gamma_2 - \frac{s}{\rho_g} \frac{d\rho_g}{dp} \right) \right] \tag{E-26}$$

$$B_{1,k} \triangleq \frac{P_{1,k}}{C_{o,k,o}^2\ \Omega_{o,k}} \left(\frac{s}{\rho_g} \frac{d\rho_g}{dp} - v_{fg}\ \gamma_2 \right) \tag{E-27}$$

Integrating Eq. (E-25) yields,

$$\delta \langle \hat{j} \rangle_k = \delta \langle \hat{j} \rangle_k^{IN} + \frac{(C_{K,o})_k^{IN}}{C_{o,k,o}\ \Omega_{o,k}} (\xi_k - 1)\ \delta \hat{\Omega}_{p,k} + [A_{1,k}(\xi_k - 1) + B_{1,k}\ \ln \xi_k]\ \delta \hat{p} \tag{E-28}$$

Perturbing and Laplace transforming Eqs. (E-4) and (E-2), respectively, to obtain,

$$\delta(\hat{C}_K)_k = C_{o,k,o}\ \delta \langle \hat{j} \rangle_k + \left(\langle j_o \rangle_k \frac{dC_{o,k}}{dp} + \frac{dV_{gj}}{dp} \right) \delta \hat{p} \tag{E-29}$$

$$(C_{K,o})_k \frac{\partial \delta \langle \hat{\alpha} \rangle_k}{\partial z} + s\ \delta \langle \hat{\alpha} \rangle_k + \frac{d \langle \alpha_o \rangle_k}{dz}\ \delta(\hat{C}_K)_k = \frac{\delta \hat{\Gamma}_k}{\rho_g} - \frac{\Gamma_{k,o}}{\rho_g^2} \frac{d\rho_g}{dp}\ \delta \hat{p} - \frac{\langle \alpha_o \rangle_k}{\rho_g}\ s \frac{d\rho_g}{dp}\ \delta \hat{p}$$

$$- \langle \alpha_o \rangle_k\ C_{o,k,o} \frac{\partial \delta \langle \hat{j} \rangle_k}{\partial z} - \langle \alpha_c \rangle_k \frac{d \langle j_o \rangle_k}{dz} \frac{dC_{o,k}}{dp}\ \delta \hat{p} - C_{o,k,o} \frac{d \langle j_o \rangle_k}{dz}\ \delta \langle \hat{\alpha} \rangle_k \tag{E-30}$$

Using Eqs. (E-12), (E-13) and (E-28), Eq. (E-30) becomes,

$$\frac{\partial \delta \langle \hat{\alpha} \rangle_k}{\partial \xi_k} + \frac{A_{2,k}}{\xi_k}\ \delta \langle \hat{\alpha} \rangle_k = \frac{P_{1,k}}{C_{o,k,o}\ \Omega_{o,k} (C_{K,o})_k^{IN}}\ \xi_k^{-3}\ \delta \hat{\Omega}_{p,k} - \frac{P_{1,k}}{(C_{K,o})_k^{IN,2}}\ \xi_k^{-3}\ \delta \langle \hat{j} \rangle_k^{IN}$$

$$+ (B_{2,k}\ \xi_k^{-1} + C_{2,k}\ \xi_k^{-2} + D_{2,k}\ \xi_k^{-3} + E_{2,k}\ \xi_k^{-3}\ \ln \xi_k)\ \delta \hat{p} \tag{E-31}$$

where,

$$A_{2,k} \triangleq 1 + \frac{s}{C_{o,k,o}\,\Omega_{o,k}} \qquad \text{(E-32)}$$

$$B_{2,k} = \frac{1}{C_{o,k,o}\,\Omega_{o,k}}[\frac{\gamma_{3,k}}{\rho_g} - \frac{\Omega_{o,k}}{\rho_g^2\,v_{fg}}\frac{d\rho_g}{dp} + \frac{\rho_f}{C_{o,k,o}\,\Delta\rho}(\frac{\gamma_2}{\rho_g} - \frac{s}{\rho_g}\frac{d\rho_g}{dp}$$

$$- \frac{C_{o,k,o}^2\,\Omega_{o,k}}{(C_{K,o})_k^{IN}}A_{1,k} - \Omega_{o,k}\frac{dC_{o,k}}{dp})] \qquad \text{(E-33)}$$

$$C_{2,k} \triangleq \frac{1}{C_{o,k,o}\,\Omega_{o,k,o}}[\frac{P_{1,k}}{C_{o,k,o}(C_{K,o})_k^{IN}}(\frac{s}{\rho_g}\frac{d\rho_g}{dp} - \frac{\gamma_2}{\rho_g}) - \frac{\rho_f\,B_{1,k}\,C_{o,k,o}\,\Omega_{o,k}}{\Delta\rho(C_{K,o})_k^{IN}}] \qquad \text{(E-34)}$$

$$D_{2,k} \triangleq \frac{P_{1,k}}{C_{o,k,o}(C_{K,o})_k^{IN,2}}[C_{o,k,o}(A_{1,k} + B_{1,k}) - \frac{dV_{gj,k}}{dp} + \frac{V_{gj,k}}{C_{o,k,o}}\frac{dC_{o,k}}{dp}] \qquad \text{(E-35)}$$

$$E_{2,k} \triangleq -\frac{P_{1,k}\,B_{1,k}}{(C_{K,o})_k^{IN,2}} \qquad \text{(E-36)}$$

Equation (E-31) can be integrated to obtain,

$$\delta\langle\hat{\alpha}\rangle_k = \xi_k^{-A_{2,k}}\,\delta\langle\hat{\alpha}\rangle_k^{IN} + \frac{P_{1,k}}{C_{o,k,o}\,\Omega_{o,k}(C_{K,o})_k^{IN}(A_{2,k} - 2)}(\xi_k^{-2} - \xi_k^{-A_{2,k}})\,\delta\hat{\Omega}_{p,k}$$

$$- \frac{P_{1,k}}{(C_{K,o})_k^{IN,2}(A_{2,k} - 2)}(\xi_k^{-2} - \xi_k^{-A_{2,k}})\,\delta\langle\hat{j}\rangle_k + \{\frac{B_{2,k}}{A_{2,k}}(1 - \xi_k^{-A_{2,k}})$$

$$+ \frac{C_{2,k}}{A_{2,k} - 1}(\xi_k^{-1} - \xi_k^{-A_{2,k}}) + \frac{D_{2,k}}{A_{2,k} - 2}(\xi_k^{-2} - \xi_k^{-A_{2,k}})$$

$$+ \frac{E_{2,k}}{A_{2,k} - 2}[\xi_k^{-2}(\ln\xi_k - \frac{1}{A_{2,k} - 2}) + \frac{1}{A_{2,k} - 2}\xi_k^{-A_{2,k}}]\}\,\delta\hat{p} \qquad \text{(E-37)}$$

APPENDIX F

DERIVATION OF EXPRESSIONS FOR $\delta\langle\hat{\bar{\rho}}\rangle$, $\delta\hat{G}$, $\delta\hat{G}'$, $\delta\hat{S}_{DC}$, and $\delta\hat{\phi}^2_{\ell o}$

$\delta\langle\hat{\bar{\rho}}\rangle$

From Eq. (2.46) we obtain,

$$\delta\langle\hat{\bar{\rho}}\rangle = -\Delta\rho\delta\langle\hat{\alpha}\rangle_k - \langle\alpha_o\rangle_k \frac{d\Delta\rho}{dp}\delta\hat{p} \tag{F-1}$$

Hence, using Eq. (B-41) yields,

$$\delta\langle\hat{\bar{\rho}}\rangle = R_{1,k}\delta\langle\hat{j}\rangle_k^{IN} + R_{2,k}\delta\langle\hat{\bar{\Omega}}\rangle_k + R_{3,k}\delta\langle\hat{\alpha}\rangle_k^{IN} + R_{4,k}\delta\hat{p} \tag{F-2}$$

where,

$$R_{i,k} \overset{\Delta}{=} -\Delta\rho\ \theta_i^{(k)} \qquad i = 1,2,3 \tag{F-3}$$

$$R_{4,k} \overset{\Delta}{=} -\Delta\rho\ \theta_4^{(k)} - \langle\alpha_o\rangle_k \frac{d\Delta\rho}{dp} \tag{F-4}$$

with, $\theta_i^{(k)}$ (i=1,2,3) defined by Eqs. (B-114)-(B-116).

$\delta\hat{G}$

Since,

$$G_k = (\rho_f - \Delta\rho\ C_o\langle\alpha\rangle_k)\ \langle j\rangle_k - \Delta\rho\ V_{gj,k}\langle\alpha\rangle_k \tag{F-5}$$

then,

$$\delta\hat{G}_k = (\rho_f - \Delta\rho\ C_{o,k,o}\langle\alpha_o\rangle_k)\ \delta\langle\hat{j}\rangle_k - \Delta\rho(C_{K,o})_k\ \delta\langle\hat{\alpha}\rangle_k + g_p\ \delta\hat{p} \tag{F-6}$$

where,

$$g_p = -\frac{d\Delta\rho}{dp}\langle\alpha_o\rangle_k\ C_{K,o} - \langle\alpha_o\rangle_k\ \Delta\rho\ \left(\frac{dC_{o,k}}{dp}\langle j_o\rangle_k + \frac{dV_{gj}}{dp}\right) \tag{F-7}$$

Using Eqs. (B-29) and (B-41), we have,

$$\delta\hat{G}_k = \{g_{1,k}\,\xi_k^{-1} + g_{2,k}\xi_k^{1-A_2}\}\delta\langle\hat{j}\rangle_k^{IN} + \{g_{3,k} + g_{4,k}\xi_k^{-1} + g_{5,k}\xi_k^{1-A_2}\}\,\delta\hat{\bar{\Omega}}_k$$

$$+ g_{6,k}\xi_k^{1-A_2}\,\delta\langle\hat{\alpha}\rangle_k^{IN} + \{g_{7,k} + g_{8,k}\xi_k + g_{9,k}\xi_k^{-1} + g_{10,k}\xi_k^{1-A_2} + g_{11,k}\xi_k^{-1}\,\ell n\xi_k\}\,\delta p \tag{F-8}$$

where $g_{i,k}$ (i=1-6) are defined in Ref. 1 [Eq. (II.8)]. The $g_{i,k}$ (i=7-11) are defined as follows,

$$g_{7,k} \triangleq A_{1s}\,(\rho_f - \Delta\rho C_{o,k,o}\langle\alpha_o\rangle_k^{IN}) - \Delta\rho(C_{K,o})_k^{IN}P_{4,k} + \frac{1}{C_{o,k,o}^2\Delta\rho}[\rho_f V_{gj}$$

$$+ (C_{K,o})_k^{IN}\,(\rho_f - \Delta\rho C_{o,k,o}\langle\alpha_o\rangle_k^{IN})](C_{o,k,o}\frac{d\Delta\rho}{dp} + \Delta\rho\,\frac{dC_{o,k,o}}{dp})$$

$$- \frac{\rho_f}{C_{o,k,o}\Delta\rho}(V_{gj}\,\frac{d\Delta\rho}{dp} + \Delta\rho\,\frac{dV_{gj}}{dp}) \tag{F-9}$$

$$g_{8,k} \triangleq - \Delta\rho(C_{K,o})_k^{IN}\,P_{3,k} - \frac{\rho_f}{C_{ok,o}^2\,\Delta\rho}(C_{K,o})_k^{IN}(C_{o,k,o}\,\frac{d\Delta\rho}{dp} + \Delta\rho\frac{dC_{oko}}{dp}) \tag{F-10}$$

$$g_{9,k} \triangleq (\rho_f - C_{o,k,o}\Delta\rho\langle\alpha_o\rangle_k^{IN})(\frac{1}{C_{o,k,o}}\,\frac{dV_{gj}}{dp} - \frac{V_{gj}}{C_{o,k,o}^2}\frac{dC_{o,k,o}}{dp} - A_{1s})$$

$$- \Delta\rho(C_{K,o})_k^{IN}(P_{5,k} + \frac{P_{6,k}}{2 - A_2}) \tag{F-11}$$

$$g_{10,k} \triangleq \Delta\rho(C_{k,o})_k^{IN}(P_{3,k} + P_{4,k} + P_{5,k} + \frac{P_{6,k}}{2 - A_2}) \tag{F-12}$$

$$g_{11,k} \triangleq (\rho_f - C_{o,k,o}\Delta\rho\langle\alpha_o\rangle_k^{IN})B_{1s} - \Delta\rho(C_{K,o})_k^{IN}\,P_{6,k} \tag{F-13}$$

$\underline{\delta\hat{G}'}$

From Eq. (2.44), we have,

$$\delta\hat{G}' = \frac{2G_o}{\langle\bar{\rho}\rangle}\,\delta\hat{G}_k - \frac{G_o^2}{\langle\bar{\rho}\rangle^2}\,\delta\langle\hat{\bar{\rho}}\rangle \tag{F-14}$$

Substituting Eqs. (F-2) and (F-6) into Eq. (F-14) yields,

$$\delta\hat{G}' = G'_{1,k}\ \delta\langle\hat{j}\rangle_k^{IN} + G'_{2,k}\ \delta\hat{\bar{\Omega}}_k + G'_{3,k}\ \delta\langle\hat{\alpha}\rangle_k^{IN} + G'_{4,k}\ \delta\hat{p} \tag{F-15}$$

where, $G'_{i,k}$ (i=1-3) are defined in Ref. 1 [Eq. (VII.5)]. The $G'_{4,k}$ is defined as,

$$\begin{aligned} G'_{4,k} &\triangleq \frac{2G_o}{\langle\bar{\rho}\rangle}\ \left(g_{7,k} + g_{8,k}\xi_k + g_{9,k}\xi_k^{-1} + g_{10,k}\xi_k^{1-A_2} + g_{11,k}\xi_h^{-1}\ell n\xi_k\right) \\ &+ \frac{G_o^2\Delta\rho}{\langle\bar{\rho}\rangle^2}\{P_{3,k}(1 - \xi_k^{-A_2}) + P_{4,k}(\xi_k^{-1} - \xi_k^{-A_2}) + P_{5,k}(\xi_k^{-2} - \xi_k^{-A_2}) \\ &+ P_{6,k}[\xi_k^{-2}(\ell n\xi_k^{-1} - \frac{1}{A_2 - 2}) + \frac{\xi_k^{-A_2}}{A_2 - 2}]\} + \frac{G_o^2\langle\alpha_o\rangle_k}{\langle\bar{\rho}\rangle^2}\cdot\frac{d\Delta\rho}{dp} \end{aligned} \tag{F-16}$$

$\delta\hat{S}_{DG}$

By Eqs. (2.45) and (2.47), we have, for the perturbation in the drift-flux spatial gradient term,

$$\delta\hat{S}_{DG,k} = 2\bar{V}'_2\ \delta\hat{V}'_{gj,k} - \bar{V}'_1\ \delta\langle\hat{\bar{\rho}}\rangle + (V'_{gj,o})^2\ \frac{\rho_f(\rho_f - \langle\bar{\rho}\rangle)}{(\langle\bar{\rho}\rangle - \rho_g)^2}\frac{d\rho_g}{dp}\ \delta\hat{p} \tag{F-17}$$

$$\delta\hat{V}'_{gj,k} = (C_{oko} - 1)\ \delta\langle\hat{j}\rangle_k + (\frac{dV_{gj,k}}{dp} + \langle j_o\rangle_k\ \frac{dC_{o,k,o}}{dp})\ \delta\hat{p} \tag{F-18}$$

where $\langle j_o\rangle_k$ can be obtained from Eq. (B-10) as,

$$\langle j_o\rangle_k = \langle j_o\rangle_k^{IN} + \frac{(C_{K,o})_k^{IN}}{C_{o,k,o}}\ (\xi_k - 1) \tag{F-19}$$

Combining Eqs. (F-17)-(F-19) and using Eqs. (B-29) and (B-47) yields,

$$\delta\hat{S}_{DG,k} = S_{1,k}\ \delta\langle\hat{j}\rangle_k^{IN} + S_{2,k}\ \delta\langle\hat{\alpha}\rangle_k^{IN} + S_{3,k}\ \delta\hat{\bar{\Omega}}_k + S_{4,k}\ \delta\hat{p} \tag{F-20}$$

where $S_{i,k}$ (i=1-4) are defined as,

$$S_{1,k} \triangleq \gamma_{1,k} + \gamma_{2,k}\xi_k^{-2} - \gamma_{2,k}\xi_k^{-A_2} \tag{F-21}$$

$$S_{2,k} \triangleq \gamma_{5,k}\xi^{-A_2} \tag{F-22}$$

$$S_{3,k} \triangleq \gamma_{3,k} - \gamma_{3,k}\xi_k + \gamma_{4,k}\xi_k^{-2} + \gamma_{4,k}\xi_k^{-A_2} \qquad \text{(F-23)}$$

$$S_{4,k} \triangleq \gamma_{6,k} + \gamma_{7,k}\xi_k + \gamma_{8,k}\xi_k^{-1} + \gamma_{9,k}\xi_k^{-2} + \gamma_{10,k}\xi_k^{-A_2} + \gamma_{11,k}\ln\xi_k$$

$$+ \gamma_{12,k}\xi_k^{-2}\ln\xi_k \qquad \text{(F-24)}$$

The definition for γ_i (i=1-5) is shown in Ref. 1 [Eq. (VII.17)]. The $\gamma_{i,k}$ (i=6-12) are defined as,

$$\gamma_{6,k} \triangleq -\bar{V}_1' \frac{\rho_f}{C_{o,k,o}\Delta\rho}\frac{d\rho_g}{dp} + \bar{V}_1'\Delta\rho P_{3,k} - 2\bar{V}_2'(C_{o,k,o} - 1)A_{1s} + \bar{V}_3' \qquad \text{(F-25)}$$

$$\gamma_{7,k} \triangleq 2\bar{V}_2'\,(C_{o,k,o} - 1)A_{1s} + \bar{V}_4' \qquad \text{(F-26)}$$

$$\gamma_{8,k} \triangleq \bar{V}_1'\left(\frac{\rho_f}{C_{o,k,o}\Delta\rho} - \langle\alpha_o\rangle_k^{IN}\right)\frac{d\rho_g}{dp} + \bar{V}_1'\Delta\rho P_{4,k} \qquad \text{(F-27)}$$

$$\gamma_{9,k} \triangleq \bar{V}_1'\Delta\rho\left(P_{5,k} + \frac{P_{6,k}}{2 - A_2}\right) \qquad \text{(F-28)}$$

$$\gamma_{10,k} \triangleq -\bar{V}_1'\Delta\rho\left(P_{3,k} + P_{4,k} + P_{5,k} + \frac{P_{6,k}}{1 - A_2}\right) \qquad \text{(F-29)}$$

$$\gamma_{11,k} \triangleq 2\bar{V}_2'\,(C_{o,k,o} - 1)B_{1s} \qquad \text{(F-30)}$$

$$\gamma_{12,k} = \bar{V}_1'\,\Delta\rho P_{6,k} \qquad \text{(F-31)}$$

$$\bar{V}_1' \triangleq \frac{\rho_f\,\rho_g(V_{gj}')^2}{(\langle\bar{\rho}\rangle^2 - \rho_g\langle\bar{\rho}\rangle)^2}\left\{2\rho_f\langle\bar{\rho}\rangle - \langle\bar{\rho}\rangle^2 - \rho_f\,\rho_g\right\} \qquad \text{(F-32)}$$

$$\bar{V}_2' \triangleq \frac{\rho_f - \langle\bar{\rho}\rangle}{\langle\bar{\rho}\rangle - \rho_g}\cdot\frac{\rho_f\,\rho_g}{\langle\bar{\rho}\rangle}V_{gj}' \qquad \text{(F-33)}$$

$$\overline{V}_3' = 2\overline{V}_2'\left[\frac{dV_{gj,k}}{dp} + \left(\langle j_o\rangle_k^{IN} - \frac{(C_{K,o})_k^{IN}}{C_{o,k,o}}\right)\frac{dC_{o,k,o}}{dp}\right] + (V_{gj}')^2\,\frac{\rho_f(\rho_f - \overline{\langle\rho\rangle})}{(\langle\overline{\rho}\rangle - \rho_g)^2}\,\frac{d\rho_g}{dp} \quad \text{(F-34)}$$

$$\overline{V}_4' \triangleq 2\overline{V}_2'\,\frac{dC_{o,k,o}}{dp}\,\frac{(C_{K,o})_k^{IN}}{C_{o,k,o}} \quad \text{(F-35)}$$

$\delta\hat{\phi}_{\ell o}^2$ (or $\delta\hat{\Phi}$)

The two-phase friction multiplier, $\phi_{\ell o}^2$, can be written as,

$$\phi_{\ell o}^2 \triangleq C_1\,\frac{v_{fg}}{v_f}\,\langle x\rangle + C_2 \quad \text{(F-36)}$$

where,

$$\langle x\rangle = \frac{\langle j\rangle}{v_{fg}\,G} - \frac{\rho_g}{\Delta\rho} \quad \text{(F-37)}$$

Substituting Eq. (F-37) into Eq. (F-36) yields,

$$\phi_{\ell o}^2 = C_1\left(\frac{\langle j\rangle}{v_f\,G} - 1\right) + C_2 \quad \text{(F-38)}$$

Perturbing Eq. (F-38) yields,

$$\delta\hat{\phi}_{\ell o}^2 = \frac{C_1\,\rho_f}{G_o}\,\delta\langle\hat{j}\rangle_k - \frac{C_1\,\rho_f\langle j_o\rangle_k}{G_o^2}\,\delta\hat{G}_k \quad \text{(F-39)}$$

Thus,

$$\begin{aligned}\delta\hat{\phi}_{\ell o}^2 = {} & \left(f_{1,k} + f_{2,k}\xi_k^{-1} + f_{3,k}\xi_k^{1-A_2} + f_{4,k}\xi_k^{2-A_2}\right)\delta\langle\hat{j}\rangle_k^{IN} + \left(f_{5,k} + f_{6,k}\xi_k^{-1}\right.\\ & \left. + f_{7,k}\xi_k + f_{8,k}\xi_k^{1-A_2} + f_{9,k}\xi_k^{2-A_2}\right)\delta\hat{\overline{\Omega}}_k + \left(f_{10,k}\xi_k^{1-A_2} + f_{11,k}\xi_k^{2-A_2}\right)\delta\langle\hat{\alpha}_k\rangle^{IN}\\ & + \left(f_{12,k} + f_{13,k}\xi_k^{-1} + f_{14,k}\xi_k + f_{15,k}\xi_k^{2} + f_{16,k}\xi_k^{1-A_2} + f_{17,k}\xi^{2-A_2}\right.\\ & \left. + f_{18,k}\ln\xi_k + f_{19,k}\xi_k^{-1}\ln\xi_k\right)\delta\hat{p}\end{aligned} \quad \text{(F-40)}$$

where $f_{i,k}$ (i=1-11) are defined in Ref. 1 [Eq. (VII.13)]. The $f_{i,k}$ (i=12-19) are defined as follows,

$$f_{12,k} \triangleq \frac{C_1 \rho_f}{G_o^2}\left[\frac{V_{gj}}{C_{o,k,o}} g_{7,k} - \frac{(C_{K,o})_k^{IN}}{C_{o,k,o}} g_{9,k} - G_o A_{1s}\right] \tag{F-41}$$

$$f_{13,k} \triangleq \frac{C_1 \rho_f V_{gj}}{G_o^2 C_{o,k,o}} g_{9,k} \tag{F-42}$$

$$f_{14,k} \triangleq \frac{C_1 \rho_f}{G_o^2}\left[\frac{V_{gj}}{C_{o,k,o}} g_{8,k} - \frac{(C_{K,o})_k^{IN}}{C_{o,k,o}} g_{7,k} + G_o A_{1s}\right] \tag{F-43}$$

$$f_{15,k} \triangleq - \frac{C_1 \rho_f (C_{K,o})_k^{IN}}{G_o^2 C_{o,k,o}} g_{8,k} \tag{F-44}$$

$$f_{16,k} \triangleq \frac{C_1 \rho_f V_{gj}}{G_o^2 C_{o,k,o}} g_{10,k} \tag{F-45}$$

$$f_{17,k} \triangleq - \frac{C_1 \rho_f (C_{K,o})_k^{IN}}{G_o^2 C_{o,k,o}} g_{10,k} \tag{F-46}$$

$$f_{18,k} \triangleq \frac{C_1 \rho_f}{G_o^2}\left[G_o B_{1s} - \frac{(C_{K,o})_k^{IN}}{C_{o,k,o}} g_{11,k}\right] \tag{F-47}$$

$$f_{19,k} \triangleq \frac{C_1 \rho_f V_{gj}}{G_o^2 C_{o,k,o}} g_{11,k} \tag{F-48}$$

The expression for the local loss multiplier, $\delta\hat{\Phi}$, is obtained as a similar expression.

APPENDIX G

DERIVATION OF THE EXPRESSIONS FOR $\delta\langle\hat{j}_p\rangle^{IN}$ AND $\delta\langle\hat{\alpha}_p\rangle^{IN}$

Assuming that no mass and energy accumulated at the upper plenum entrance, we have,

$$w_p^{IN} = \sum_{j=1}^{N} w_j^{OUT} \qquad \text{(G-1)}$$

$$w_p^{IN}\, h_p^{IN} = \sum_{j=1}^{N} w_j^{OUT}\, h_j^{OUT} \qquad \text{(G-2)}$$

Since,

$$h_p^{IN} = h_f + \langle x_p\rangle^{IN} h_{fg} \qquad \text{(G-3)}$$

$$h_j^{OUT} = h_f + \langle x_j\rangle^{OUT} h_{fg} \qquad \text{(G-4)}$$

then, substituting Eqs. (G-3) and (G-4) into Eq. (G-2), we obtain,

$$\langle x_p\rangle^{IN} = \sum_{j=1}^{N} w_j^{OUT}\, \langle x_j\rangle^{OUT}/w_p^{IN} \qquad \text{(G-5)}$$

From the Zuber-Findlay void-quality relationship,(3) we have,

$$\langle\alpha\rangle\left(C_o \frac{\rho_g}{\rho_f} + \frac{\rho_g\, V_{gj}}{G}\right) = \langle x\rangle\left(1 - \langle\alpha\rangle\, C_o \frac{\Delta\rho}{\rho_f}\right) \qquad \text{(G-6)}$$

Perturbing and Laplace transforming Eq. (G-6),

$$\delta\langle\hat{x}\rangle = F_1'\, \delta\langle\hat{j}\rangle + F_2'\, \delta\langle\hat{\alpha}\rangle + F_3'\, \delta\hat{p} \qquad \text{(G-7)}$$

where,

$$F_1' \triangleq -\frac{\rho_f\, \rho_g \langle\alpha_o\rangle\, V_{gj,o}}{G_o^2} \qquad \text{(G-8)}$$

$$F_2' = \left(C_o \frac{\rho_g}{\rho_f} + \frac{\rho_g V_{gj}}{G_o} + \frac{\langle x_o\rangle C_o \Delta\rho}{\rho_f} + \frac{\langle \alpha_o\rangle \rho_g \Delta\rho V_{gj} C_{K,o}}{G_o^2}\right) / \left(1 - \langle \alpha_o\rangle C_o \frac{\Delta\rho}{\rho_f}\right) \tag{G-9}$$

$$\begin{aligned} F_3' \triangleq & - \{\langle \alpha_o\rangle \frac{d\rho_g}{dp}[\frac{C_o}{\rho_f}(\langle x_o\rangle - 1) \frac{V_{gj,o}}{G_o}(1 - \frac{\rho_g \langle \alpha_o\rangle C_{K,o}}{G_o})] \\ & - \frac{\langle \alpha_o\rangle}{\rho_f} \frac{dC_o}{dp}(\rho_g + \langle x_o\rangle \langle \alpha_o\rangle \Delta\rho + \frac{\rho_f \rho_g V_{gj} \Delta\rho \langle j_o\rangle \langle \alpha_o\rangle}{G_o^2} \\ & - \frac{\langle \alpha_o\rangle \rho_g}{G_o} \frac{dV_{gj}}{dp}(1 + \frac{V_{gj} \langle \alpha_o\rangle \Delta\rho}{G_o})\} / (1 - \langle \alpha_o\rangle C_o \frac{\Delta\rho}{\rho_f}) \end{aligned} \tag{G-10}$$

From Eqs. (G-1) and (G-5), we obtain,

$$w_{p,o}^{IN} = \sum_{j=1}^{N} w_{j,o}^{OUT} \triangleq w_o \tag{G-11}$$

$$\langle X_p\rangle_o^{IN} = \sum_{j=1}^{N} w_{j,o}^{OUT} \langle x_j\rangle_o^{OUT} / w_o \tag{G-12}$$

$$\delta \hat{w}_p^{IN} = \sum_{j=1}^{N} \delta \hat{w}_j^{OUT} \tag{G-13}$$

$$\delta \langle \hat{x}_p\rangle^{IN} = \sum_{j=1}^{N} [w_{j,o}^{OUT} \, \delta \langle \hat{x}\rangle_j^{OUT} + (\langle x_j\rangle_o^{OUT} - \langle x_p\rangle_o^{IN}) \, \delta \hat{w}_j^{OUT}] / w_o \tag{G-14}$$

Using Eq. (G-7), we have,

$$\delta \langle \hat{x}_j\rangle^{OUT} = F_{1,j}' \, \delta \langle \hat{j}_j\rangle^{OUT} + F_{2,j}' \, \delta \langle \hat{\alpha}_j\rangle^{OUT} + F_{3,j}' \, \delta \hat{p} \tag{G-15}$$

where,

$$F_{1,j}' \triangleq - \frac{\rho_f \rho_g \langle \alpha_o\rangle_j^{OUT} V_{gj,j,o}}{G_{j,o}^2} \tag{G-16}$$

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$$F'_{2,j} \triangleq \left(C_{o,j} \frac{\rho_g}{\rho_f} + \frac{\rho_g V_{gj,j}}{G^2_{j,o}} + \frac{\langle x_o\rangle_j^{OUT} C_{o,j} \Delta\rho}{\rho_f} + \frac{\langle\alpha_o\rangle_j \rho_g \Delta\rho V_{gj,j} C_{K,o,j}}{G^2_{j,o}}\right)/$$

$$\left(1 - \langle\alpha_o\rangle_j^{OUT} C_{o,j} \frac{\Delta\rho}{\rho_f}\right) \tag{G-17}$$

$$F'_{3,j} \triangleq - \{\langle\alpha_o\rangle_j^{OUT} \frac{d\rho_g}{dp}[\frac{C_{o,j}}{\rho_f}(\langle x_o\rangle_j^{OUT} - 1) - \frac{V_{gj,o,j}}{G_{jo}}(1 - \frac{\rho_g \langle\alpha_o\rangle_j C_{K,o,j}}{G_{jo}})]$$

$$- \frac{\langle\alpha_o\rangle_j}{\rho_f} \frac{dC_{j,o}}{dp}(\rho_g + \langle x_o\rangle_j^{OUT} \langle\alpha_o\rangle_j^{OUT} \Delta\rho + \frac{\rho_f \rho_g V_{gj} \Delta\rho \langle j_o\rangle_j^{OUT} \langle\alpha_o\rangle_j^{OUT}}{G^2_{j,o}})$$

$$- \frac{\langle\alpha_o\rangle_j^{OUT} \rho_g}{G_{j,o}} \frac{dV_{gj,j}}{dp}(1 + \frac{V_{gj,j} \langle\alpha_o\rangle_j^{OUT} \Delta\rho}{G_{j,o}})\}/(1 - \langle\alpha_o\rangle_j^{OUT} C_{o,j} \frac{\Delta\rho}{\rho_f})$$

$$\tag{G-18}$$

Using Eq. (G-7) with $C_o = 1$ and $V_{gj} = 0$, yields,

$$\delta\langle\hat{x}\rangle_p^{IN} = F'_{1,p} \delta\langle\hat{j}_p\rangle^{IN} + F'_{2,p} \delta\langle\hat{\alpha}\rangle_p^{IN} + F'_{3,p} \delta\hat{p} \tag{G-19}$$

where,

$$F'_{1,p} \triangleq 0 \tag{G-20}$$

$$F'_{2,p} \triangleq \left(\frac{\rho_g}{\rho_f} + \frac{\langle x_p\rangle_o^{IN} \Delta\rho}{\rho_f}\right)/\left(1 - \langle\alpha_p\rangle_o^{IN} \frac{\Delta\rho}{\rho_f}\right) \tag{G-21}$$

$$F'_{3,p} = - \langle\alpha_p\rangle_o^{IN} \frac{d\rho_g}{dp} \frac{1}{\rho_f}(\langle x_p\rangle_o^{IN} - 1)/\left(1 - \langle\alpha_p\rangle_o^{IN} \frac{\Delta\rho}{\rho_f}\right) \tag{G-22}$$

Substituting Eqs. (G-15) and (G-19) into Eq. (G-14), yields,

$$\delta\langle\hat{\alpha}_p\rangle^{IN} = \sum_{j=1}^{N} F_{1,j} \delta\langle\hat{j}\rangle_j^{OUT} + \sum_{j=1}^{N} F_{2,j} \delta\langle\hat{\alpha}\rangle_j^{OUT} + \sum_{j=1}^{N} F_{3,j} \delta\hat{w}_j^{OUT} + F_4 \delta\hat{p} \tag{G-23}$$

where,

$$F_{1,j} \triangleq \frac{w_{j,o}^{OUT} \, F'_{1,j}}{w_o \, F'_{2,p}} \tag{G-24}$$

$$F_{2,j} \triangleq \frac{w_{j,o}^{OUT} \, F'_{2,j}}{w_o \, F'_{2,p}} \tag{G-25}$$

$$F_{1,j} \triangleq \frac{\langle x_{j,o} \rangle_o^{OUT} - \langle x_p \rangle_o^{IN}}{w_o \, F'_{2,p}} \tag{G-26}$$

$$F_4 \triangleq \sum_{j=1}^{N} \frac{w_{j,o}^{OUT} \, F'_{3,j}}{w_o \, F'_{2,j}} - \frac{F'_{3,p}}{F'_{2,p}} \tag{G-27}$$

Taking into account that,

$$\delta \hat{w}_j^{OUT} = A_{xs,j} \, \delta \hat{G}_j^{OUT} \tag{G-28}$$

and,

$$\delta \hat{w}_p^{IN} = A_p \, \delta \hat{G}_p^{IN} \tag{G-29}$$

and substituting Eqs. (G-28) and (G-29) into Eq. (G-13) yields,

$$\delta \hat{G}_p^{IN} = \sum_{j=1}^{N} \frac{A_{xs,j}}{A_p} \, \delta \hat{G}_j^{OUT} \tag{G-30}$$

By using Eq. (F-6), we have,

$$\delta \hat{G}_j^{OUT} = \left(\rho_f - \Delta\rho \, C_{o,j} \langle \alpha_j \rangle_o^{OUT} \right) \delta \langle \hat{j}_j \rangle^{OUT} - \Delta\rho \left(C_{k,o} \right)_j^{OUT} \delta \langle \hat{\alpha}_j \rangle^{OUT} + g_{p,j} \, \delta \hat{p} \tag{G-31}$$

and,

$$\delta \hat{G}_p^{IN} = \left(\rho_f - \Delta\rho \langle \alpha_p \rangle_o^{IN} \right) \delta \langle \hat{j}_p \rangle^{IN} - \Delta\rho \langle j_p \rangle_o^{IN} \delta \langle \hat{\alpha}_p \rangle^{IN} + g_{p,p} \, \delta \hat{p} \tag{G-32}$$

Substituting Eqs. (G-31) and (G-32) into Eq. (G-30) yields,

$$\delta\langle\hat{j}\rangle_p^{IN} = \sum_j^N J_{1,j}\ \delta\langle\hat{j}\rangle_j^{OUT} + \sum_j^N J_{2,j}\ \delta\langle\hat{\alpha}\rangle_j^{OUT} + \sum_j^N J_{3,j}\ \delta\hat{w}_j^{OUT} + J_4\ \delta\hat{p} \qquad \text{(G-33)}$$

where,

$$J_{1,j} \triangleq [\frac{A_{xs,j}}{A_p}(\rho_f - \Delta\rho\ C_{o,j}\langle\alpha_j\rangle_o^{OUT}) + \Delta\rho\langle j_p\rangle_o^{IN}\ F_{1,j}]/(\rho_f - \Delta\rho\langle\alpha_p\rangle_o^{IN})$$

$$+ J_{3,j}\ A_{xs,j}\ \rho_j' \qquad \text{(G-34)}$$

$$J_{2,j} \triangleq [- \frac{A_{xs,j}}{A_p}\ \Delta\rho(C_{K,o})_j^{OUT} + \Delta\rho\langle j_p\rangle_o^{IN}\ F_{2,j}]/(\rho_f - \Delta\rho\langle\alpha_p\rangle_o^{IN})$$

$$- J_{3,j}\ A_{xs,j}\ g_j' \qquad \text{(G-35)}$$

$$J_{3,j} \triangleq \Delta\rho\langle j_p\rangle_o^{IN}\ F_{3,j}/(\rho_f - \Delta\rho\langle\alpha_p\rangle_o^{IN}) \qquad \text{(G-36)}$$

$$J_4 \triangleq [\sum_j^N \frac{A_{xs,j}}{A_p}\ g_{p,j} + \Delta\rho\langle j_p\rangle_o^{IN}\ F_4 - g_{p,p}]/(\rho_f - \Delta\rho\langle\alpha_p\rangle) + J_{3,j}\ A_{xs,j}\ g_{p,j} \qquad \text{(G-37)}$$

By Eqs. (B-151) and (B-152), we have,

$$\delta\langle\hat{j}\rangle_j^{OUT} = B_{1,N_j,j}\ \delta\hat{j}_{in,j} + B_{2,N_j,j}^{1\phi} \sum_{\ell}^{L_j} H_{\ell,j}'\ \delta\hat{q}_{\ell,j}''' + \sum_{i=D}^{K_j} B_{2,N_j,j}^{i}\ \delta\hat{q}_{i,j}'''$$

$$+ B_{3,N_j,j}\ \delta\hat{h}_{in} + B_{4,N_j,j}\ \delta\hat{p} \qquad \text{(G-38)}$$

$$\delta\langle\hat{\alpha}\rangle_j^{OUT} = K_{1,N_j,j}\ \delta\hat{j}_{in,j} + K_{2,N_j,j}^{1\phi} \sum_{\ell}^{L_j} H_{\ell,j}'\ \delta\hat{q}_{\ell,j}''' + \sum_{i=D}^{K_j} K_{2,N_j,j}^{i}\ \delta\hat{q}_{i,j}'''$$

$$+ K_{3,N_j,j}\ \delta\hat{h}_{in} + K_{4,N_j,j}\ \delta\hat{p} \qquad \text{(G-39)}$$

and,

$$\delta\hat{w}_j^{OUT} \triangleq A_{xs,j}\ \delta\hat{G}_j^{OUT} = \rho_j'\ A_{xs,j}\ \delta\langle\hat{j}\rangle_j^{OUT} - g_j'\ A_{xs,j}\ \delta\langle\hat{\alpha}\rangle_j^{OUT} + g_{p,j}\ A_{xs,j}\ \delta\hat{p} \qquad \text{(G-40)}$$

where ρ_j', g_j', and $g_{p,j}$ will be defined later.

Substituting Eqs. (G-38)-(G-40) into Eq. (G-33), yields,

$$\delta\langle\hat{j}\rangle_p^{IN} = \sum_{j=1}^{N} B_{1,j}^{*}\ \delta\hat{j}_{in,j} + \sum_{j=1}^{N} B_{2,j}^{*1\phi} \sum_{\ell}^{L_j} H'_{\ell,j}\ \delta\hat{q}'''_{\ell,j} + \sum_{j=1}^{N} \sum_{i=D}^{K_j} B_{2,j}^{*i}\ \delta\hat{q}'''_{i,j}$$

$$+ B_3^{*}\ \delta\hat{h}_{in} + B_4^{*}\ \delta\hat{p} \qquad \text{(G-41)}$$

where,

$$B_{1,j}^{*} \triangleq (J_{1,j} + J_{3,j}\ \rho'_j\ A_{xs,j})\ B_{1,N_j,j} + J_{2,j}^{*}\ K_{1,N_j,j} \qquad \text{(G-42)}$$

$$B_{1,j}^{*1\phi} \triangleq (J_{1,j} + J_{3,j}\ \rho'_j\ A_{xs,j})\ B_{2,N_j,j}^{1\phi} + J_{2,j}^{*}\ K_{1,N_j,j}^{1\phi} \qquad \text{(G-43)}$$

$$B_{2,j}^{*i} \triangleq (J_{1,j} + J_{3,j}\ \rho'_j\ A_{xs,j})\ B_{2,N_j,j}^{i} + J_{2,j}^{*}\ K_{1,N_j,j}^{i} \qquad \text{(G-44)}$$

$$B_3^{*} \triangleq \sum_{j=1}^{N} [(J_{1,j} + J_{3,j}\ \rho'_j\ A_{xs,j})\ B_{3,N_j,j} + J_{2,j}^{*}\ K_{3,N_j,j}] \qquad \text{(G-45)}$$

$$B_4^{*} \triangleq \sum_{j=1}^{N} [(J_{1,j} + J_{3,j}\ \rho'_j\ A_{xs,j})\ B_{4,N_j,j} + J_{2,j}^{*}\ K_{4,N_j,j} + J_{3,j}\ A_{xs,j} g_{p,j}] + J_4 \qquad \text{(G-46)}$$

Similarly, Eq. (G-23) becomes,

$$\delta\langle\hat{\alpha}\rangle_p^{IN} = \sum_{j=1}^{N} K_{1,j}^{*}\ \delta\hat{j}_{in,j} + \sum_{j=1}^{N} K_{2,j}^{*1\phi} \sum_{j=1}^{L_j} H'_{\ell,j}\ \delta\hat{q}'''_{\ell,j} + \sum_{j=1}^{N} \sum_{i=D}^{K_j} K_{2,j}^{*i}\ \delta\hat{q}'''_{i,j}$$

$$+ K_3^{*}\ \delta\hat{h}_{in} + K_4^{*}\ \delta\hat{p} \qquad \text{(G-47)}$$

where,

$$K_{1,j}^{*} \triangleq (F_{1,j} + F_{3,j}\ \rho'_j\ A_{xs,j})\ B_{1,N_j,j} + F_{2,j}^{*}\ K_{1,N_j,j} \qquad \text{(G-48)}$$

$$K_{2,j}^{*1\phi} \triangleq (F_{1,j} + F_{3,j}\ \rho'_j\ A_{xs,j})\ B_{2,N_j,j}^{1\phi} + F_{2,j}^{*}\ K_{2,N_j,j}^{1\phi} \qquad \text{(G-49)}$$

$$K_{2,j}^{*i} \triangleq (F_{1,j} + F_{3,j}\ \rho'_j\ A_{xs,j})\ B_{2,N_j,j}^{i} + F_{2,j}^{*}\ K_{2,N_j,j}^{i} \qquad \text{(G-50)}$$

$$K_3^* \triangleq \sum_{j=1}^{N} [(F_{1,j} + F_{3,j}\, \rho_j'\, A_{xs,j})\, B_{3,N_j,j} + F_{2,j}^*\, K_{3,N_j,j} \qquad \text{(G-51)}$$

$$K_4^* \triangleq \sum_{j=1}^{N} [(F_{1,j} + F_{3,j}\, \rho_j'\, A_{xs,j})\, B_{4,N_j,j} + F_{2,j}^*\, K_{4,N_j,j} + F_{3,j}\, A_{xs,j}\, g_{p,j}] + F_4 \qquad \text{(G-52)}$$

$$J_{2,j}^* \triangleq J_{2,j} - J_{3,j}\, A_{xs,j}\, g_j' \qquad \text{(G-53)}$$

$$F_{2,j}^* \triangleq F_{2,j} - F_{3,j}\, A_{xs,j}\, g_j' \qquad \text{(G-54)}$$

$$\rho_j' \triangleq \rho_f - \Delta\rho\, C_{o,j}\, \langle\alpha_j\rangle_o^{OUT} \qquad \text{(G-55)}$$

$$g_j' \triangleq \Delta\rho (C_{K,o})_j^{OUT} \qquad \text{(G-56)}$$

APPENDIX H

DERIVATION OF THE EXPRESSIONS FOR $\delta\langle\hat{j}_R\rangle^{IN}$ AND $\delta\langle\hat{\alpha}_R\rangle^{IN}$

We assume that no mass and energy are accumulated at the riser inlet (where we switch from a homogeneous flow model to a slip flow model). The continuity equation and energy conservation equations, respectively, at the upper plenum/riser interface are,

$$G_R^{IN} A_R = G_{II}^{OUT} A_R \tag{H-1}$$

$$G_R^{IN} A_R h_R^{IN} = G_{II}^{OUT} A_R h_p^{OUT} \tag{H-2}$$

Taking into account that,

$$h = h_f + \langle x\rangle h_{fg} \tag{H-3}$$

Eqs. (H-1) and (H-2) yield,

$$\langle x_R\rangle^{IN} = \langle x_{II}\rangle^{OUT} \tag{H-4}$$

For steady-state,

$$G_{R,o}^{IN} = G_{II,o}^{OUT} = \frac{A_p}{A_R} G_{II,o}^{IN} \tag{H-5}$$

$$\langle x_R\rangle_o^{IN} = \langle x_{II}\rangle_o^{OUT} \tag{H-6}$$

From the Zuber-Findlay void-quality relationship, we get,

$$\langle \alpha_R\rangle_o^{IN} = \frac{\langle x_R\rangle_o^{IN}}{C_{o,R}\left(\frac{\rho_g}{\rho_f} + \langle x_R\rangle_o^{IN}\frac{\Delta\rho}{\rho_f}\right) + \frac{\rho_g V_{gj,R}}{G_{R,o}^{IN}}} \tag{H-7}$$

Also, we have,

$$\langle j_R\rangle_o^{IN} = \frac{G_{0,R}^{IN} + \Delta\rho\, V_{gj}\langle \alpha_R\rangle_o^{IN}}{\rho_f - \Delta\rho\, C_{o,R}\langle \alpha_R\rangle_o^{IN}} \tag{H-8}$$

Perturbing and Laplace transforming Eq. (H-4) yields,

$$\delta\langle\hat{x}_R\rangle^{IN} = \delta\langle\hat{x}_{II}\rangle^{OUT} \tag{H-9}$$

Applying Eq. (G-7) to the interface between the riser and upper plenum, we obtain,

$$\delta\langle\hat{x}_R\rangle^{IN} = F'_{1,R}\,\delta\langle\hat{j}_R\rangle^{IN} + F'_{2,R}\,\delta\langle\hat{\alpha}_R\rangle^{IN} + F'_{3,R}\,\delta\hat{p} \tag{H-10}$$

$$\delta\langle\hat{x}_{II}\rangle^{OUT} = F'_{1,p}\,\delta\langle\hat{j}_{II}\rangle^{OUT} + F'_{2,p}\,\delta\langle\hat{\alpha}_{II}\rangle^{OUT} + F'_{3,p}\,\delta\hat{p} \tag{H-11}$$

Combining Eqs. (H-9)-(H-11), we obtain,

$$F'_{1,R}\,\delta\langle\hat{j}_R\rangle^{IN} + F'_{2,R}\,\delta\langle\hat{\alpha}_R\rangle^{IN} = F'_{1,p}\,\delta\langle\hat{j}_{II}\rangle^{OUT} + F'_{2,p}\,\delta\langle\hat{\alpha}_{II}\rangle^{OUT}$$

$$+ (F'_{3,p} - F'_{3,R})\,\delta\hat{p} \tag{H-12}$$

From Eq. (H-1), we have,

$$\delta\hat{G}_R^{IN} = \delta\hat{G}_{II}^{OUT} \tag{H-13}$$

By Eq. (F-6),

$$\delta\hat{G} = g_1\,\delta\langle\hat{j}\rangle + g_2\,\delta\langle\hat{\alpha}\rangle + g_p\,\delta\hat{p} \tag{H-14}$$

where,

$$g_1 \triangleq \rho_f - \Delta\rho\, C_{o,j}\langle\alpha_o\rangle \tag{H-15}$$

$$g_2 \triangleq -\Delta\rho\, C_{K,o} \tag{H-16}$$

Therefore, applying Eq. (H-14) to Eq. (H-13) yields,

$$g_{1,R}\,\delta\langle\hat{j}_R\rangle^{IN} + g_{2,R}\,\delta\langle\hat{\alpha}_R\rangle^{IN} = g_{1,p}\,\delta\langle\hat{j}_{II}\rangle^{OUT} + g_{2,p}\,\delta\langle\hat{\alpha}_{II}\rangle^{OUT}$$

$$+ (g_{p,p} - g_{p,R})\,\delta\hat{p} \tag{H-17}$$

Solving Eqs. (H-12) and (H-17) for $\delta\langle\hat{j}_R\rangle^{IN}$ and $\delta\langle\hat{\alpha}_R\rangle^{IN}$, we obtain,

$$\delta\langle\hat{j}_R\rangle^{IN} = J'_{1,R}\;\delta\langle\hat{j}_{II}\rangle^{OUT} + J'_{2,k}\;\delta\langle\hat{\alpha}_{II}\rangle^{OUT} + J'_{3,R}\;\delta\hat{p} \qquad \text{(H-18)}$$

$$\delta\langle\hat{\alpha}_R\rangle^{IN} = K'_{1,R}\;\delta\langle\hat{j}_{II}\rangle^{OUT} + K'_{2,k}\;\delta\langle\hat{\alpha}_{II}\rangle^{OUT} + K'_{3,R}\;\delta\hat{p} \qquad \text{(H-19)}$$

where,

$$J'_{1,R} \triangleq \frac{1}{\Delta}\left(g_{2,R}\,F'_{1,p} - g_{1,p}\,F'_{2,R}\right) \qquad \text{(H-20)}$$

$$J'_{2,R} \triangleq \frac{1}{\Delta}\left(g_{2,R}\,F'_{2,p} - g_{2,p}\,F'_{2,R}\right) \qquad \text{(H-21)}$$

$$J'_{3,R} \triangleq \frac{1}{\Delta}\left[g_{2,R}\left(F'_{3,p} - F'_{3,R}\right) - \left(g_{p,p} - g_{p,R}\right)F'_{2,R}\right] \qquad \text{(H-22)}$$

$$\delta\langle\hat{\alpha}_R\rangle^{IN} \triangleq K'_{1,R}\;\delta\langle\hat{j}_{II}\rangle^{OUT} + K'_{2,R}\;\delta\langle\hat{\alpha}_{II}\rangle^{OUT} + K'_{3,R}\;\delta\hat{p} \qquad \text{(H-23)}$$

$$K'_{1,R} \triangleq \frac{1}{\Delta}\left(-\,g_{1,R}\,F'_{1,p} + g_{1,p}\,F'_{1,R}\right) \qquad \text{(H-24)}$$

$$K'_{2,R} \triangleq \frac{1}{\Delta}\left(-\,g_{1,R}\,F'_{2,p} + g_{2,p}\,F'_{1,R}\right) \qquad \text{(H-25)}$$

$$K'_{3,R} \triangleq \frac{1}{\Delta}\left[-\,g_{1,R}\left(F'_{3,p} - F'_{3,R}\right) - \left(g_{p,p} - g_{p,R}\right)F'_{1,R}\right] \qquad \text{(H-26)}$$

$$\Delta \triangleq F'_{1,R}\,g_{2,R} - F'_{2,R}\,g_{1,R} \qquad \text{(H-27)}$$

From Eqs. (2.135) and (2.136), we have,

$$\delta\langle\hat{j}_{II}\rangle^{OUT} = \frac{A_p}{A_R}\,\delta\langle\hat{j}_I\rangle^{OUT} + \frac{V_R}{A_R}\,C_{1,UP}\;\delta\hat{p} \qquad \text{(H-28)}$$

$$\delta\langle\hat{\alpha}_{II}\rangle^{OUT} = \delta\langle\hat{\alpha}_I\rangle^{OUT}\,e^{-\dfrac{s\,V_R}{\langle j_p\rangle_o^{IN}\,Ap}} + \frac{C_{2,UP}}{s}\left(1 - e^{-\dfrac{s\,V_R}{\langle j_p\rangle_o^{IN}\,Ap}}\right)\delta\hat{p} \qquad \text{(H-29)}$$

Substituting Eqs. (H-28) and (H-29) into Eqs. (H-18) and (H-19) yields,

$$\delta\langle\hat{j}_R\rangle^{IN} = J_{1,R}\ \delta\langle\hat{j}_I\rangle^{OUT} + J_{2,R}\ \delta\langle\hat{\alpha}_I\rangle^{OUT} + J_{3,R}\ \delta\hat{p} \qquad \text{(H-30)}$$

and,

$$\delta\langle\hat{\alpha}_R\rangle^{IN} = K_{1,R}\ \delta\langle\hat{j}_I\rangle^{OUT} + K_{2,R}\ \delta\langle\hat{\alpha}_I\rangle^{OUT} + K_{3,R}\ \delta\hat{p} \qquad \text{(H-31)}$$

where,

$$J_{1,R} \triangleq J'_{1,R}\frac{A_p}{A_R} \qquad \text{(H-32)}$$

$$J_{2,R} \triangleq J'_{2,R}\ e^{-\frac{sV_R}{\langle j_p\rangle_o^{IN} Ap}} \qquad \text{(H-33)}$$

$$J_{3,R} \triangleq J'_{1,R}\frac{V_R}{A_R}C_{1,UP} + J'_{2,R}\frac{C_{2,UP}}{s}\left(1 - e^{-\frac{sV_R}{\langle j_p\rangle_o^{IN} Ap}}\right) + J'_{3,R} \qquad \text{(H-34)}$$

$$K_{1,R} \triangleq K'_{1,R}\frac{A_p}{A_R} \qquad \text{(H-35)}$$

$$K_{2,R} \triangleq K'_{2,R}\ e^{-\frac{sV_R}{\langle j_p\rangle_o^{IN} Ap}} \qquad \text{(H-36)}$$

$$K_{3,R} \triangleq K'_{1,R}\frac{V_R}{A_R}C_{1,UP} + K'_{2,R}\frac{C_{2,UP}}{s}\left(1 - e^{-\frac{sV_R}{\langle j_p\rangle_o^{IN} Ap}}\right) + K'_{3,R} \qquad \text{(H-37)}$$

Finally, using Eqs. (2.108) and (2.112), Eqs. (H-30) and (H-31), respectively, become,

$$\delta\langle\hat{j}_R\rangle^{IN} = J^{*}_{1,R}\ \delta\langle\hat{j}_p\rangle^{IN} + J^{*}_{2,R}\ \delta\langle\hat{\alpha}_p\rangle^{IN} + J^{*}_{3,R}\ \delta\hat{p} \qquad \text{(H-38)}$$

$$\delta\langle\hat{\alpha}_R\rangle^{IN} = K^*_{1,R}\ \delta\langle\hat{j}_p\rangle^{IN} + K^*_{2,R}\ \delta\langle\hat{\alpha}_p\rangle^{IN} + K^*_{3,R}\ \delta\hat{p} \tag{H-39}$$

where,

$$J^*_{1,R} \triangleq J_{1,R} \tag{H-40}$$

$$J^*_{2,R} \triangleq J_{2,R}\ e^{-\frac{s\Delta Z_p}{\langle j_p\rangle_o^{IN}}} \tag{H-41}$$

$$J^*_{3,R} \triangleq J_{1,R}\ C_{1,up}\ \Delta Z_p + J_{2,R}\frac{C_{2,UP}}{s}\left(1 - e^{-\frac{s\Delta Z_p}{\langle j_p\rangle_o^{IN}}}\right) + J_{3,R} \tag{H-42}$$

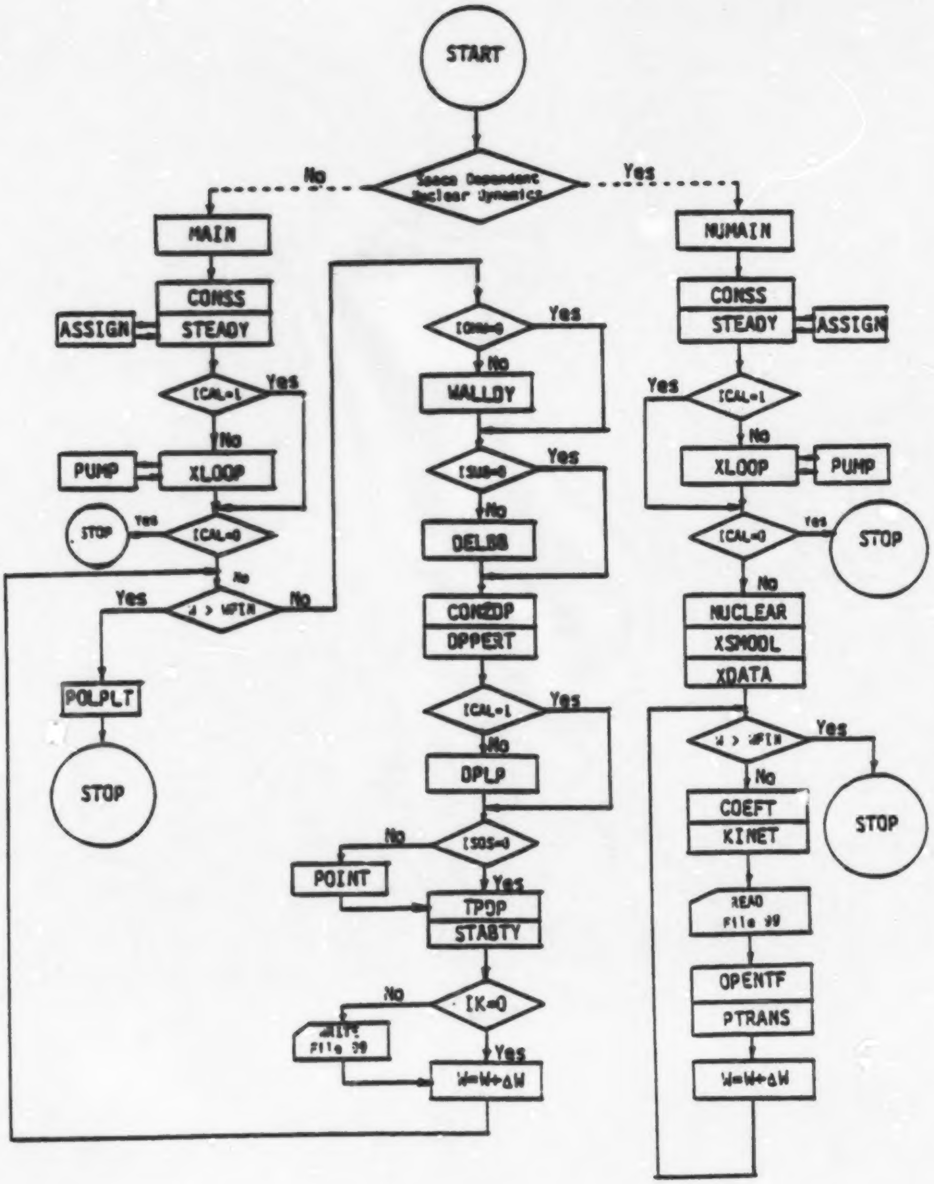
$$K^*_{1,R} \triangleq K_{1,R} \tag{H-43}$$

$$K^*_{2,R} \triangleq K_{2,R}\ e^{-\frac{s\Delta Z_p}{\langle j_p\rangle_o^{IN}}} \tag{H-44}$$

$$K^*_{3,R} \triangleq K_{1,R}\ C_{1,UP}\ \Delta Z_p + K_{2,R}\frac{C_{2,UP}}{s}\left(1 - e^{-\frac{s\Delta Z_p}{\langle j_p\rangle_o^{IN}}}\right) + K_{3,R} \tag{H-45}$$

APPENDIX I

FLOW CHART OF NUFREQ-NP


START
Space Dependent Nuclear Dynamics
No
Yes
MAIN
CONSS
STEADY
ASSIGN
ICAL=1
Yes
No
PUMP
XLOOP
STOP
Yes
ICAL=0
No
Yes
W > WFIN
No
POLPLT
STOP
ICMM=0
Yes
No
WALLDY
ISUB=0
Yes
No
DELBB
CONZDP
DPPERT
ICAL=1
Yes
No
DPLP
No
ISOS=0
POINT
Yes
TPDP
STABTY
No
IK=0
WRITE File 99
Yes
W=W+ΔW
NUMAIN
CONSS
STEADY
ASSIGN
Yes
ICAL=1
No
XLOOP
PUMP
ICAL=0
Yes
STOP
No
NUCLEAR
XSMODL
XDATA
W > WFIN
Yes
No
STOP
COEFT
KINET
READ File 99
OPENTF
PTRANS
W=W+ΔW

APPENDIX J

SUBROUTINES AND FUNCTIONS IN NUFREQ-NP

1. Subroutines

CONSS	Calculates the steady-state system and channel parameters which are independent of axial node.
STEADY	Computes the steady-state nodal thermal-hydraulic parameters in the core channels.
ASSIGN	Node index and node size will be reassigned by the void departure point or the bulk boiling boundary.
XLOOP	Calculates the steady-state thermal-hydraulic parameters in the recirculating loop and prepares frequency-independent values for loop stability analysis.
PUMP	Computes the required pump head or pump characteristics.
CON2DP	Prepares the frequency-dependent constants for the two-phase pressure drop perturbation calculation.
DELBB	Calculates the transfer functions for boiling boundary perturbation.
WALLDY	Calculate the transfer functions of heated wall dynamics for various wall geometries.
DPPERT	Calculates the transfer functions of pressure drop perturbation and void fraction perturbation for the parallel channels analysis.
DPLP	Calculates the transfer functions of the pressure drop perturbation in the recirculating loop.
VDTF	Calculation of the thermal-hydraulic transfer functions.
POINT	Calculates point kinetics zero-power reactor transfer function
TPDP	Calculates thermal-hydraulic partial transfer functions
STABTY	Calculates the open-loop or the closed-loop transfer functions and the stability margins corresponding to various external forcing functions for point kinetics, and output thermal hydraulic transfer functions for space dependent neutron kinetics used in NU-system.

PTRANS	Calculates open-loop or closed-loop transfer functions corresponding to various external forcing functions if space dependent neutron kinetics used.
POLPLT	Plotting subroutines for Nyquist plot.
LINE	
XLINE	
YLINE	
PTTY	
PRTPLE4	
NUCLER	Reads 3-dimensional power and exposure distribution.
XSMODL	Reads nuclear data for reference void fraction and exposure, and calculates fitting coefficients of data at certain exposure and void fraction.
XDATA	Fits the nuclear data for certain exposure and void fraction.
COEFT	Calculate nodal nuclear parameters for the steady-state and for the transient case.
KINET	Generates kinetics parameters for given geometries.
OPENTF	Calculates open-loop transfer function by the Gauss reduction method.
MATXIN	Matrix inversion by matrix partition method.
MATMUL	Matrix multiplication.
PMXIV	Matrix inversion using MTS Library Package (IMSL).
PMXMUL	Matrix multiplication associated PMXIV.
LEQ2C	Linear equation-complex matrix solver in MTS Library (IMSL).

2. Functions

HL	Liquid Enthalpy (Btu/lb).
DENS	Liquid density (lb/ft^3)
VF	Specific volume of saturated liquid (ft^3/lb)
VFG	$v_{fg} = v_g - v_f$(ft^3/lb)
HF	Saturated liquid enthalpy (Btu/lb)
HFG	h_{fg}

MULT	Viscosity of saturated liquid (lb/ft-hr).
COND	Thermal conductivity of saturated liquid (Btu/ft- F-hr).
MARNELL	Calculation of $\pi(p,G)$ in the Martinelli-Nelson correlation, Eq. (2.11), for the two-phase friction loss multiplier.
SGMA	Surface tension of water (lb_f/ft).
ANGL(Z)	Argument of complex value z.
CCOTH(Z)	Coth(z) for complex z.
EPOW(X,Z)	x^z for real x and complex z.
BSI0(Z)	Modified Bessel Function of the first kind of order 0 for complex z.
BSI1(Z)	Modified Bessel Function of the first kind of order 1 for complex z.
BSK0(Z)	Modified Bessel Function of the second kind of order 0 for complex z.
BSK1(Z)	Modified Bessel Function of the second kind of order 1 for complex z.
BER	Ber function.
BEI	Bei function.
BEIS	Bei' function.
BERS	Ber' function.
RKER	Ker function.
RKEI	Kei function.
RKEIS	Kei' function.
RKERS	Ker' function.
DRFDP	$d\rho_f/\rho$
DVG1	dv_g/dp
DHF1	dh_f/dp
DHG1	dh_g/dp
DCZER1	dC_o/dp

DVGJ1	dV_{gj}/dp
DRGDP	$d\rho_g/dp$
DVFGDP	dv_{fg}/dp
DTSDP	dT_{sat}/dp
DHFGDP	dh_{fg}/dp

APPENDIX K

INPUT/OUTPUT DESCRIPTION

NUFREQ-NP INPUT

The input file 5 can be used in both thermal hydraulic program system (TH-system) and nuclear program system (NU-system). To run NU-system, the other two files, file 4 and 7 should also be supplied.

1. Input for System Geometry and Thermal Properties (FILE = 5)

	Variables	Description
CARD1	COMM1	TITLE
	COMM2	COMMENTS
	(8I4)	NEUTRONIC OPTIONS AND SPECIFICATIONS OF CHANNEL
	ICASE*=1	Point kinetics (uniform), core average
	=2	Point kinetics accounting the radially non-uniform nuclear properties
	=3	Point kinetics accounting the axially non-uniform nuclear properties
	=4	Radially coupled kinetics
	=5	Axially coupled kinetics, identical channel
	=6	Axially coupled kinetics, averaged channel
	=7	Point kinetics accounting the radially non-uniform nuclear properties in the specific channel
	=8	General space kinetics (3-D), checker board subject to specific channel
	=9	Point kinetics (uniform), specific channel
	=10	Radially coupled kinetics, checkerboard subject to specific channel
	=11	Point kinetics accounting the radially non-uniform nuclear properties in the checkerboard

---

*In fact, ICASE is inactive in TH-system. The recommended value for ICASE is 999 for TH-system.

	Variables	Description
	=12	Point kinetics (uniform), checkerboard
	=13	Two group axially coupled kinetics, specific channel (coarse mesh diffusion theory, CMDT)
	=999	Point kinetics. Axial power distribution should be supplied by user
	ISPEC	Number of row of specific channel (<15)
	JSPEC	Number of column of specific channel (<15)
	IRUN =0	Stop computing
	=1	Continue computing with different data set
	ICAL =0	Only steady-state calculation
	=1	Parallel channel analysis
	=2	Recirculating loop analysis without inlet enthalpy feedback
	=3	Same as ICAL=2, but with inlet enthalpy feedback
	=4	Calculation of power-to-void fraction transfer function
	=5	Calculation of power-to-void fraction transfer function including the inlet enthalpy feedback
	=6	Calculation of power-to-flow transfer function
CARD4	(8I4)	Nodal configuration
	NCH	Total number of channels
	NODES	Total number of axial nodes in a channel (<30)
	NSP	Total number of spacers

	Variables		Description
CARD5 CARD6	COMM2 (8I4)		OPTIONS
	IOSUB	=0	Bulk boiling only
		=1	Subcooled boiling
	IOHW	=0	No heated wall dynamics
		=1	Lumped parameter model
		=2	Distributed parameter model for parallel plates
		=3	Distributed parameter model for cylindrical tube
		=4	Distributed parameter model for BWR fuel rods
	IO2Q	=0	No heat flux perturbation in the two-phase region
		=1	Include heat flux perturbation in the two-phase region
	IK	=0	NU-system skipped
		=1	File 99 is outputed from TH-system. File 99 is read in NU-system
	ISI		Number of significant figure in rounding values of oscillation period
	IREG	=0	Next frequency is automatically adjusted by a factor of WMULT
		=1	WMULT is simply multiplied
		=2	WMULT is simply added
	IBODE	=0	Calculate the open-loop transfer function in NU-system. Plot Nyquist plot and calculate stability margins in TH-system for poing kinetics if DELK (or DELP) $\neq 0$. If DELK $= 0$, they are calculated for DELVI $\neq 0$ case.
		=1	Calculate the closed-loop transfer function in NU-system. No Nyquist plot and stability margin calculated.

	Variables	Description
	IPRINT=0	All steady-state values are not printed
	=1	Only the pressure drop of each node is printed
	=2	Only void fraction and flow velocity are printed
	=3	Only channel geometry is printed
	=4	Void fraction and pressure drop will be printed
	=5	Void fraction, pressure drop, axial power and heat flux distribution are printed
	=6	All of steady-state values are printed
CARD7	(8I4)	OPTIONS (CONTINUED)
	IPILO =0	C_1 and C_2 in Eq. (F-27) will be specified by user
	=1	C_1 and C_2 will be calculated by Martinelli-Nelson empirical correlation
	ISLIP =0	Use constant drift-flux parameters
	=1	Use variable drift-flux parameters (Ohkawa/Lahey)
	IRW =0	Channel inlet flow velocities are fixed by input
	=1	Channel inlet flow velocities will be redistributed (channel inlet flow velocities given by input will be initially guessed values)
CARD8	COMM8	
CARD9	(6E10.4)	
	POWER	Total thermal power (MWt)
	BYPOWF	Bypass coolant power fraction
	BYFLWF	Bypass coolant flow fraction

	Variables	Description
CARD10 CARD11	COMM3 (6E10.4)	CORE THERMAL PARAMETERS
	p	System pressure (psia)
	TIN	Inlet coolant temperature (°F)
	ALHEAT	Heated channel length, i.e., active fuel length (ft)
	TSATP	Saturation temperature corresponding to p (°F)
	AVEQ	Core averaged volumetric heat generation rate (Btu/hr-ft^3)
CARD12	(6E10.4)	CORE PARAMETERS (SKIPPED, IF IRW=0)
	DPGS	Constant core pressure drop initially guessed (psia)
	WIN	Core inlet flow rate, w_0-w_{bypass} (Mlb/hr)
CARD13 CARD14	COMM5 (6E10.4)	CHANNEL PARAMETERS
	CZERO	Void concentration parameter, if ISLIP=0 and ICVGJ=0 (refer to CARD 7 and CARD 51)
	VGJ	Drift velocity (ft/s), if ISLIP=0 and ICVGJ=0
	DELX	Channel radial size (cm)
	DELZ	Channel axial size (ft)
	CHOMO1	C_1 in Eq. (F-27)
	CHOMO2	C_2 in Eq. (F-27)
CARD15	(6E10.4)	EMPIRICAL CONSTANTS FOR TWO-PHASE HEAT TRANSFER COEFFICIENT
	CKI	K in Eq. (A-8)
	CMP	m in Eq. (A-8) (e.g., m=4 for Jens-Lottes correlation)

	Variables	Description
CARD16 CARD17	COMM8 (2E12.6)	SPACERS (SKIPPED IF NSP=0)
	ZSP(N)	Locations of spacers (ft)
	KLOSS(N)	Local loss coefficients of spacers
CARD18 CARD19	COMM9 (6E10.4)	THERMAL PARAMETERS FOR LOOP ANALYSIS (SKIP TO CARD30 IF ICAL IS LESS THAN UNITY)
	AXSCH	Total core flow area (ft^2)
	AP	Flow area of the upper plenum (ft^2)
	RAR	Total flow area of the riser (ft^2)
	RPO	Chopped length of the upper plenum, a in Fig.3 (ft)
	RP1	Upper location of Region I in Fig.3 (ft)
	RP2	Upper location of Region II in Fig.3 (ft)
CARD20	(8F10.4)	
	ZLUP	Upper plenum flow path elevation (ft)
	FLUP	Upper plenum flow path length (ft)
CARD21 CARD22	COMM10 (6E10.4)	RISER PARAMETERS
	COR	Void concentration parameter for the riser
	VGJR	Drift velocity for the riser (ft/s)
	RL	Upper location of the riser (ft)
	AR	Total flow area of the riser (ft^2)
	DRIN	Hydraulic diameter of a riser (in)
	RKIN	Local loss coefficient at the inlet of the riser
	RKEXIT	Local loss coefficient at the exit of the riser

	Variables	Description
CARD23	(8F10.4)	
	ZLR	Riser flow path elevation (ft)
	FLR	Riser flow path length (ft)
CARD24	COMM	STEAM SEPARATOR PARAMETERS
CARD25	(8F10.4)	Ref. to Eq. (2.262)
	XINER	$\tilde{\ell}/\tilde{A}$ (ft^{-1})
	XLSEP	ℓ_{sep} (ft)
	XKSEP	K_{sep}
	XASEP	A_{ss} (ft^{2})
	YLSEP	Gravity elevation (ft)
	DHSEP	Hydraulic diameter (ft)
	CSEP	Two-phase friction multiplier
CARD	COMM	STEAM DOME PARAMETERS
CARD	(6E10.4)	
	ADOME	Area of steam dome (ft^{2})
	VDOME	Volume of steam dome (ft^{3})
	TURB	$\frac{dG}{Gdp}$, G is the mass flux (lbm/sec) from steam dome to turbine. p in psia.
CARD26	COMM13	PARAMETERS IN THE SINGLE-PHASE PORTION OF THE EX-CORE LOOP
CARD26	(6E10.4)	
	SLOOP	$\Sigma \frac{L_i}{A_f}$ in Eq. (2.327) (ft^{-1})
	SFLOOP	$\Sigma \frac{f_i L_i}{D_{H,i} A_i^2} + \frac{K_i}{A_i^2}$ in Eq. (2.328) (ft^{-4})

	Variables	Description
	AA	Slope of pump curve (psi-s/lb) in Eq. (2.324)
	AD	Flow area of control volume 1 (liquid phase) in Fig. 5 (ft^2)
	DL	Path length of control volume 1 (liquid phase) (ft)
	DHDL	Hydraulic diameter of control volume 1 (liquid phase) (ft)
	WO	Total recirculating flow rate (10^6lb/hr)
	RATW	Total number of channel groups of interest in the core
CARD28 CARD29	COMM13 (6E10.4)	THERMAL PARAMETERS OF INLET ENTHALPY FEEDBACK (SKIP TO CARD30, IF ICAL IS NOT 3)
	HFW	Enthalpy of feedwater (Btu/lb)
	ADC	Flow area of the downcomer (ft^2)
	PHV	Heated perimeter of the vessel (ft)
	DKV	Thermal conductivity of the vessel wall (Btu/lb-°F-s)
	CPV	Specific heat of the vessel wall (Btu/lb-°F)
	DENV	Density of the vessel wall (lb/ft^3)
	TEMV	Temperature of the vessel wall (°F)
	TEMINV	Inlet coolant temperature of the downcomer (°F)
	THV	Thickness of the vessel wall (ft)
	HOD	Heat transfer coefficient in the downcomer (Btu/ft^2-°F-hr)
	DLENG	Length of the downcomer (ft)
CARD30 CARD31	COMM13 (6E10.4)	LOWER PLENUM PARAMETERS
	PLM	Mass of coolant in the lower plenum (lb)
	AHLP	Heated area in the lower plenum (ft)
	THLP	Thickness of the vessel wall in the lower plenum (ft)

	Variables	Description
	HOLP	Heat transfer coefficient in the lower plenum (Btu/ft^2-°F-hr)
CARD32		RECIRCULATION LOOP PATH GEOMETRY
CARD33	(8F10.4)	
	ADLP	Flow area in lower plenum (ft^2)
	DHLP	Hydraulic diameter in lower plenum (ft)
	ZLLP	Flow path elevation in lower plenum (ft)
	FLLP	Flow path length in lower plenum (ft)
	XKLP	Irreversible loss coefficient in lower plenum
CARD34	(8F10.4)	
	AD1	Flow area in control volume 1 (liquid phase)
	DH1	Hydraulic diameter in control volume 1 in Fig.5 (ft)
	ZL1	Flow path elevation in control volume 1 in Fig.5 (ft)
	FL1	Flow path length in control volume 1 in Fig.5 (ft)
	XK1	Irreversible loss coefficient in control volume 1 in Fig. 5
CARD35	(8F10.4) AD2 DH2 ZL2 FL2 XK2	Same as CARD32, but for control volume 2
CARD36	(8F10.4) AD3 DH3 ZL3 FL3 XK3	Same as CARD32, but for control volume 3

	Variables	Description
CARD37	(I4,F10.0)	PUMP (ref. to CARD 51)
	IPUMP=0	SPUMP supplied by user
	=1	SPUMP calculated by program
	SPUMP	PUMP parameter, e.g., pump speed fraction in jet pump
CARD38 CARD39	COMM4 (8I4)	CHANNEL THERMAL PARAMETERS
	JRR	Number of channel types (<5)
CARD40	NN(J) (6E10.4)	Number of channels of channel type J
	VEL3D(J)	Channel inlet velocity (ft/s)
	PH(J)	Heated perimeter (ft)
	AXS(J)	Channel flow area (ft^2)
	DHIN(J)	Hydraulic diameter (in)
	CXF(J)	Cross-sectional area of the heater (ft^2)
	XKIN(J)	Local loss coefficient at the channel inlet
	XKEXIT(J)	Local loss coefficient at the channel exit
	RPWR(J)	Relative power fraction associated with channel type J
CARD41 CARD42	COMM4 (6E10.4)	CORE POWER DENSITY PROFILE (SKIPPED IF IK IS NOT ZERO
	Q3D(I,J)	Power density parameter
CARD43 CARD44	COMM6 (6E10.4)	PERTURBATION PARAMETER
	DELVI	If not zero, channel inlet flow velocity is externally oscillating
	DELQO	If not zero, core-average power density is externally oscillated with the magnitude of |DELQO|
	DELK	If not zero, reactivity is externally oscillated
	DELP	If not zero, system pressure is externally oscillated

	Variables	Description
CARD45	(8I4)	SWITCHES FOR COOLANT PROPERTIES DERIVATIVE WITH RESPECT TO SYSTEM PRESSURE (SKIPPED AS DELP=0)
	IDCZC=0	$dC_o/dp = 0$
	≠0	dC_o/dp used
	IDVGJC=0	$dV_{gj}/dp = 0$
	≠0	dV_{gj}/dp used
	IDCZR=0	$dC_o/dp = 0$ in riser
	≠0	dC_o/dp used in riser
	IDVGJR=0	$dV_{gj}/dp = 0$ in riser
	≠0	dV_{gj}/dp used in riser
CARD46	(8I4)	(SKIPPED AS DELP=0)
	IDRHOG=0	$d\rho_g/dp = 0$
	≠0	$d\rho_g/dp$ used
	IDHF=0	$dh_f/dp = 0$
	≠0	dh_f/dp used
	IDHG=0	$dh_g/dp = 0$
	≠0	dh_g/dp used
CARD47	(I4)	FREQUENCY INTERVALS
	IWC	Number of frequency intervals
CARD48	(6E10.4)	
	PWFIN(I)	Final frequency (rad/s) for frequency interval I
	PWINT(I)	Initial frequency (rad/s) for frequency interval I
	PWMULT(I)	Multiplication factor of frequency (rad/s) for frequency interval I
CARD49	COMM18 (6E10.4)	HEATED WALL DYNAMICS PARAMETERS
	1) IOHW=1	LUMPED PARAMETER HEATER
	CPH	Specific heat (Btu/lb-°F)
	DENSH	Density (Btu/ft)
	2) IOWH=2	FOR PARALLEL PLATE HEATER
	CPH	Specific heat (Btu/lb-°F)

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	Variables	Description
	TKH	Thermal conductivity (Btu/ft-°F-s)
	DENSH	Density (Btu/ft^3)
	THICKH	Heater wall thickness (ft)
	3) IOHW=3	FOR CYLINDRICAL TUBE HEATER
	CPH TKH DENSH	Same as above
	CRI	Heater inner radius (ft)
	CRO	Heater outer radius (ft)
	4) IOHW=4	
	CPH TKH DENSH	Same as above, but for fuel pin
	CPC TKC DENSC	Same as above, but for clad
	CRS	Fuel pin radius (ft)
	CRI	Inner radius of clad (ft)
	CRO	Outer radius of clad (ft)
	GAPC	Gap conductance (Btu/ft-°F-hr)
CARD50		AUXILIARY PARAMETERS
CARD51	ICE(I4)=0	Void coefficient calculated by program
	≠0	Void coefficient supplied by user
	CKCAAL (F10.0)	Void coefficient
	IV(I4)=0	SLOOP, SFLOOP, and AA supplied by user
	≠0	SLOOP, SFLOOP, and AA calculated by program
	ICVGJ(I4)=0	C_o, V_{gj} supplied by user (ref. CARD14)
	≠0	C_o, V_{gj} calculated by program
	IKEY(I4)	Redundant

	Variables	Description
	IDRF(I4)=0	$d\rho_f/dp=0$
	≠0	$d\rho_f/dp$ used
	XWK(F10.5)	1/k dk/dp in Eqs. (A-8) and (A-10)
	XWM(F10.5)	Redundant
CARD52	(8I4)	
	ICD	Redundant
	ISOS	Redundant
	IW=0	Flux weighting not applied in point kinetics as ICASE=999
	=1	ϕ^2 weighting applied in point kinetics as ICASE=999
	IPX	Redundant
	IENT=0	Integration method of liquid phase enthalpy equation used in NUFREQ-N
	≠0	New integration method (recommended)
	IRSLIP=0	C_o, V_{gj} in riser calculated by program
	≠0	C_o, V_{gj} in riser supplied by user (ref. CARD22)
CARD53	(6E10.4)	
	PCAPLA	Neutron generation time (sec)

2. PUMP: A user supplied subroutine for pump in the recirculation loop. A typical PUMP based on reference 12 is built in.

3. Input for Nuclear Data (FILE = 4)

	Variables	Description
CARD1	NFTMX (10I3,50X)	Total number of fuel type

	Variables	Description
CARD2	(3F10.4,50X)	
	REFE(I)	3 reference exposures
	REFU(I)	3 reference void fractions
CARD3	TITLE (20X,3E15.6)	NUCLEAR CROSS SECTION DATA ARRAY FOR 3 REFERENCE VOID FRACTIONS AND 3 REFERENCE EXPOSURES (IG: GROUP INDES; IE: EXPOSURE INDEX; IU: VOID FRACTION INDEX). READ FOR EVERY FUEL TYPE
	FLUX	Neutron flux, Φ (neutrons/cm^2-s)
	SIGA	Absorption cross section, Σ_a (cm^{-1})
	SIGF (cm^{-1})	$\nu\Sigma_f$
	VN2	Thermal neutron velocity, v (cm/s)
	DIFF	Diffusion coefficient, D (cm)
	SIG12	Removal cross section, (cm^{-1})
CARD4	(20X,6E10.4)	CONTINUED
	BT	Delayed neutron yield fraction (IGR: delayed neutron group index; IGR = 1,2,3,4,5,6)

4. Input for 3-D Core Composition and Power and Exposure Distribution (FILE = 7)

	Variables	Description
CARD1	TITLE (8I5)	CORE COMPOSITION
	IMAX	Maximum number of rows in 1/4 core
	JMAX	Maximum number of column in 1/4 core
	KMAX	Total number of axial nodes
	INUCLR	Nodal method option
	=0	CMDT is used
	=1	MCMDT is used
	NFTYPE	Total number of fuel type

	Variables	Description
	ICHEK	Checkerboard option (if ICHEK is not 0, it is checkerboard problem)
CARD2	PLAMDA(J) (8F10.4)	DECAY CONSTANT OF 6-GROUP DELAYED NEUTRONS
	FPDF(J)	ϵ_ℓ in Table 4.1 of Ref. (1)
	FPLAM(J)	$\lambda^{(\ell)}$ in Table 4.1 of Ref. (1)
CARD3	(15I5)	
	JMX(I)	Total number of channels in the ith row for 1/4 core
	JJMX(I)	Total number of channels in the ith for for 1/8 core
CARD4	NFUEL(I,J) (15I5)	Fuel type indexing for 1/8 core
CARD5	NCONTL(I,J) (15I5)	Total number of uncontrolled nodes in (i,j) channel for 1/8 core
CARD6	(8F10.4)	ALBEDO ASSIGNMENT
	AL(I,J)	Node albedo (has value only for core boundary nodes)
	TAL(I,J)	Upper plane albedo of channel top nodes
	BAL(I,J)	Lower plane albedo of channel bottom nodes
CARD7	(I2,1X,11F7.4)	POWER DISTRIBUTION FOR 1/8 CORE
	ASRC(I,J)	Normalized radial peaking factor
	SRC(I,J,K)	3-D power distribution
CARD8	(I2,1X,11F7.4)	EXPOSURE DISTRIBUTION FOR 1/8 CORE
	AEXP(I,J)	Channel-average exposure
	REXP(I,J,K)	3-D exposure distribution
CARD9	AXSRC(K) (10F8.4)	Normalized peaking factor of core-averaged power

NUFREQ-NP OUTPUT

	Variables	Description
LIST1		AUXILIARY DATA
LIST2		SYSTEM THERMAL PROPERTIES (P, TIN, TSATP, ALHEAT, AVEQ, NCH, NODES)
LIST3		CHANNEL TYPE DESCRIPTION
LIST4		OPTION DESCRIPTION; IOSUB, IOHW, IO2Q, IK, ISI, IREQ, IBODE
LIST5		EXTERNAL FORCING FUNCTION; DELVI, DELQO, DELK, DELP
LIST6		COOLANT PROPERTIES WHICH ARE CALCULATED IN SUBROUTINE CONSS: ENTHT (h_{in}); ENTHP (h_f); DENSF (ρ_f); VFG1 (v_{fg}); ROHG (ρ_g); TSATP (T_{sat}); TAVE (T_{ave}); VISC (ν); CPF (c_{pf}); KF (k_f); SIGM (σ)
LIST7		CHANNEL THERMAL-HYDRAULIC PARAMETERS
LIST8		PARAMETERS OF HEATED WALL DYNAMICS WHICH ARE GIVEN IN INPUT CARD49 CORRESPONDING TO HEATER GEOMETRY OPTION, IOHW
LIST9		HEAT FLUX POWER DENSITY AND TEMPERATURE DISTRIBUTIONS
	TL(K)	Liquid phase temperature (°F)
	TWALL(K)	Heater wall temperature (°F)
LIST10		NODE THERMAL PROPERTIES
	I	Node index
	DZ(I,K)	Axial node size (ft)
	K1(I,K)	Node characteristic frequency in phase change (s^{-1})
	COH(I,K)	Node void concentration parameter
	VGJH(I,K)	Node drift velocity (ft/s)
	ALFNOD(I,K)	Node average void fraction

	Variables	Description
	XEXIT(I,K)	Node exit wuality
	AVGH(K)	Node average enthalpy (Btu/lb)
	JOIN(K)	Node inlet velocity (ft/s)
LIST11		LOCAL PRESSURE DROP TERMS
	ZSP(I)	Spacer location (ft)
	KLOSS(I)	Local loss coefficient
	DFSP(I)	Local pressure drop (psid)
LIST12		NODAL STEADY-STATE PRESSURE DROP EXPRESSED BY THE GRAVITATIONAL, FRICTIONAL AND ACCELERATION TERMS
LIST13		UPPER PLENUM DESCRIPTION
LIST14		RISER DESCRIPTION INCLUDING THE FOLLOWING QUANTITIES
	GOR	Mass flux in the riser (lb/hr-ft^2)
	VRO	Steady-state volumetric flux (ft/s)
	ALPRO	Steady-state void fraction
	CORPR	Two-phase friction loss multiplier
LIST15		STEAM SEPARATOR DESCRIPTION
LIST16		PARAMETERS FOR SINGLE-PHASE LOOP; SLOOP, SFLOOP, AA
LIST17		PARAMETERS FOR INLET ENTHALPY PERTURBATION FEEDBACK WHICH ARE GIVEN IN INPUT CARD28
LIST18		LOWER PLENUM DESCRIPTION
LIST19		DOWNCOMER DESCRIPTION
LIST20		PRESSURE DROPS IN RECIRCULATION LOOP

LIST21 VARIOUS TRANSFER FUNCTIONS (IF DELP≠0, OR ICASE=999)

SYSTEM PRESSURE PERTURBATION -- $\frac{\delta\hat{\phi}/\phi_o}{\delta\hat{p}_{core}}$

CLOSED LOOP, REACTIVITY PERTURBATION -- $\frac{\delta\hat{\phi}/\phi_o}{\delta\hat{k}_{ext}}$

OPEN LOOP, REACTIVITY PERTURBATION -- $(-\frac{\delta\hat{k}_f}{\delta\hat{k}_t})$

POWER DENSITY TO AVERAGE INLET FLOW --

$$\frac{\delta\hat{W}_{core,in}/W_{core,o}}{\delta\hat{Q}/Q_o}$$

	Variables	Description
LIST22		NYQUIST PLOT
LIST23		STABILITY MARGINS
	STM	Gain margin (db)
	STA	Phase margin (degrees)

SAMPLE PROBLEM

INPUT AND OUTPUT

```
 DATA FOR LOOP ANALYSIS FOR PEACH BOTTOM UNIT 2
   * CASE PT3: 59.2% RATED POWER & 38.0% RATED FLOW RATE
* ICASE,(I,J),IRUN,ICAL ; NCH,NODES,NSP
999   1   1   1   3   1
764  24   7
* NU, IIW, 2Q, IK, ISI, IREG, IBODE,IPRINT;IPI,ISLIP,IRW
  1   4   1   0   1   2   0   6
  1   0   0
* POWER, BYPOWF, BYFLWF
  1948.     .02       .08
* P,TIN,ALHEAT,TSATP,AVEQ; DPGS,WIN(IF IRW .NE. 0)
  1005.0     533.5     12.0     545.2   1.0545+07
* CZERO, VGJ, DELX, DELZ, C1, C2 ; K,M
   1.156    1.1748     15.24     0.5        1.0       1.0
1.8661-03    4.
* LOCAL LOSS COEFFICIENT
       1.6        1.04
       3.2        1.04
       4.8        1.04
       6.4        1.04
       8.0        1.04
       9.6        1.04
      11.2        1.04
* UPPER PLENUM:AXSCH,AP,RAR,RPO,RP1,RP2 ; ZLUP,FLUP
  82.3446   254.4     42.3        2.582     16.276    17.166
   5.166      5.166
* RISER:COR,VGJR,RL,AR,DRIN,RKIN,RKEXIT ; ZLR,FLR
   1.156    1.1748    22.006      42.3        6.06        .14
   .14
   4.438     4.438
* STEAM SEPARATOR:XINER,XLSEP,XKSEP,XASEP,YLSEP,DHSEP,CSEP
   0.5      7.792    4.121      89.01    0.0        .505       1.
* STEAM DOME: ADOME,VDOME,TURB
   85.0      2327.4 1.6667E-04
* 1-P LOOP:SLOOP,SFLOOP,AA,AD,DL,DHDL ; WO,RATW
0.7000-00 1.3670-03-1.7590-04  156.50       5.375      .813
38.9          1.
* DOWNCOMMER:HFW,ADC,PHV,DKV,CPV,DENV,TEMV,TEMINV,THV,HOD,DLENG
  482.4      296.8      65.7116 2.6389-03      0.12   498.
  500.       517.        0.5365 1.3597+03     31.361
* PLM,AHLP,THLP,HOLP ; A,DH,Z,FL,XK FOR LP,D1,D2,D3; IPUMP,SPUMP
 177422.     123.8      0.625    9.9972+02
  123.8      4.19       8.767        8.767      0.00
  156.5      0.813      5.375        5.375      0.00
  296.8      2.841      15.006      15.006      0.00
   8.60      0.742      16.355      16.355      0.00
   1     .20
*  CHANNEL TYPE DESCRIPTION
   1
764
  2.392     7.2223    1.0874-01     0.5811     .06081   27.8
   .14        1.00
* AXIAL POWER DISTRIBUTION FOR CHANNEL TYPE 1
  0.55        0.72        0.84        0.90       0.95
  1.00        1.05        1.12        1.24       1.30
  1.33        1.36        1.33        1.28       1.26
  1.22        1.17        1.10        1.02       0.93
  0.84        0.68        0.52        0.29
* PERT. PARA.(V,Q,K,P)& FREQUENCY
   0.        0.          0.          1.
   1    1    1    1
   1    1    1
   7
   .628      .1256      .1256
   1.        .7         .1
   1.884     1.256      .314
   2.512     2.198      .314
   2.65      2.65       .314
   3.454     2.826      .314
   6.28      3.768      .628
 * FUEL PARAMETERS
 7.7354-02 5.6369-04   650.52  5.4580-02 2.5230-03   410.17
 1.9875-02 2.0375-02 2.3458-02  2000.
   0    -.075      0    1    1    0   .00444    4.
   1    1    1    0    1    1
   0   .00005    -.00001



1                              DATA FOR LOOP ANALYSIS FOR PEACH BOTTOM UNIT 2


LOOP OPTION IV=  0   ICVGJ =  1   IKEY=  1   IDRF=  0  XWK,XWM=     0.00444      4.00000
ICO=  1  ISOS=  1  IW= 1  IPX= 0  IENT= 1  IRSLIP=  1  IVOCAL=  0
NEUTRON LIFETIME(SEC)= 0.5000E-04     DOPPLER COEF.= -.1000E-04


POWER = 0.1948E+04 MWT
  BYPASS POWER FRACTION = 0.2000E-01  BYPASS FLOW FRACTION= 0.8000E-01


 SYSTEM PARAMETERS

      P = SYSTEM PRESSURE (PSIA) =    1005.00
      TIN = INLET TEMPERATURE (DEG-F) =     533.50
     SATURATION TEMPERATURE CORRESPONDING TO P (F) =   545.20
     ACTIVE FUEL (HEATER) LENGTH (FT) =    12.0000
     CORE AVERAGE VOLUMETRIC HEAT  =0.292917E+04

     TOTAL NUMBER OF CHANNELS  =   764
     TOTAL NUMBER OF NODES IN CHANNEL =   24


OPTION
     IOSUB  =    1
     IOHW  =    4
     IO2Q  =    1
     IK  =   0
     ISI  =    1
     IREG =    2
     IBODE=    0



EXTERNAL PERTURBATION

     ** DELDP   =       1.000**
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```

          ***** SYSTEM PROPERTIES *****
 &CALPRO
 ENTHT=527.65503,ENTHP=543.28076,DENSF=46.720047,DENSI=47.107269,VFG1=.42015821,RHOG=2.2636881,
 &END
 &PROPTY
 TSATP=545.19995,TAVE=539.34985,HFG1=649.36353,VISC=.64159074E-04,CPF=1.2613564,KF=.91731970E-04,SIGM=.12239399E-02,
 &END


CHANNEL GEOMETRY & BOILING BOUNDARY

TYPE  FLOW AREA  HEAT PERI.  HYDR.DIAM.  BOIL.BNDY.  FUEL AREA       VIN         KIN         KEXIT     POWER DIS.
  1  0.1087E+00  0.7222E+01  0.4842E-01  0.4500E+01  0.6081E-01  0.2392E+01  0.2780E+02  0.1400E+00  0.1000E+01



HEATED WALL DYNAMICS PARAMETER

     ***   HOMOGENIZED FUEL ASSEMBLY   ***

       * FUEL REGION
          SPECIFIC HEAT OF FUEL    =0.773540E-01(BTU/LB-F)
          THERMAL CONDUCTIVITY     =0.563690E-03(BTU/S-FT-F)
          DENSITY OF FUEL          = 650.5200(LB/FT3)
          FUEL RADIUS              =    0.0199(FT)

       * CLAD REGION
          SPECIFIC HEAT OF CLAD    =0.545800E-01(BTU/LB-F)
          THERMAL CONDUCTIVITY     =0.252300E-02(BTU/S-FT-F)
          DENSITY OF CLAD          = 410.1699(LB/FT3)
          INNER RADIUS OF CLAD     =    0.0204(FT)
          OUTER RADIUS OF CLAD     =    0.0235(FT)

       GAP CONDUCTANCE          =0.555556E+00(BTU/FT2-F)



          NODE           Z        HEAT FLUX        POWER DENSITY         TL            TWALL

          ***** TWO-PHASE REGION *****

            1         0.5000      13.5646        0.161104E+04        534.13        554.43

            2         1.0000      17.7572        0.210900E+04        536.89        555.08

            3         1.5000      20.7168        0.246050E+04        539.56        555.46

            4         2.0000      22.1966        0.263625E+04        541.73        555.64

            5         2.5000      23.4297        0.278271E+04        543.25        555.79

            6         3.0000      24.6629        0.292917E+04        544.20        555.92

            7         3.5000      25.8960        0.307563E+04        544.73        556.05

            8         4.0000      27.6224        0.328067E+04        545.01        556.23

            9         4.5000      30.5819        0.363217E+04        545.12        556.51

          10        5.0000      32.0617      0.380792E+04      545.20      556.65
          11        5.5000      32.8016      0.389579E+04      545.20      556.71
          12        6.0000      33.5415      0.398367E+04      545.20      556.78
          13        6.5000      32.8016      0.389579E+04      545.20      556.71
          14        7.0000      31.5685      0.374933E+04      545.20      556.60
          15        7.5000      31.0752      0.369075E+04      545.20      556.56
          16        8.0000      30.0887      0.357358E+04      545.20      556.47
          17        8.5000      28.8555      0.342713E+04      545.20      556.35
          18        9.0000      27.1292      0.322208E+04      545.20      556.18
          19        9.5000      25.1561      0.298775E+04      545.20      555.98
          20       10.0000      22.9365      0.272412E+04      545.20      555.73
          21       10.5000      20.7168      0.246050E+04      545.20      555.46
          22       11.0000      16.7707      0.199183E+04      545.20      554.94
          23       11.5000      12.8247      0.152317E+04      545.20      554.30
          24       12.0000       7.1522      0.849458E+03      545.20      553.07


NODE PROPERTIES

    NODE    DELZ       K1          CO(Z)     VGJ(Z)    AVG.VOID  XEXIT(Z)     AVG.ENTH.      JOIN
       1   0.5000   0.9826E-01    1.1560    1.1748    0.0065   0.10478E-02   0.52932E+03   0.2392E+01
       2   0.5000   0.2387E+00    1.1560    1.1748    0.0281   0.35961E-02   0.53279E+03   0.2441E+01
       3   0.5000   0.4299E+00    1.1560    1.1748    0.0681   0.81924E-02   0.53617E+03   0.2561E+01
       4   0.5000   0.6193E+00    1.1560    1.1748    0.1238   0.14774E-01   0.53891E+03   0.2777E+01
       5   0.5000   0.7920E+00    1.1560    1.1748    0.1880   0.23186E-01   0.54082E+03   0.3086E+01
       6   0.5000   0.9368E+00    1.1560    1.1748    0.2536   0.33130E-01   0.54201E+03   0.3481E+01
       7   0.5000   0.1050E+01    1.1560    1.1748    0.3158   0.44275E-01   0.54269E+03   0.3948E+01
       8   0.5000   0.1159E+01    1.1560    1.1748    0.3723   0.56563E-01   0.54304E+03   0.4472E+01
       9   0.5000   0.1302E+01    1.1560    1.1748    0.4240   0.70478E-01   0.54318E+03   0.5049E+01
      10   0.5000   0.1378E+01    1.1560    1.1748    0.4701   0.85143E-01   0.54328E+03   0.5703E+01
      11   0.5000   0.1410E+01    1.1560    1.1748    0.5096   0.10015E+00   0.54328E+03   0.6392E+01
      12   0.5000   0.1441E+01    1.1560    1.1748    0.5432   0.11549E+00   0.54328E+03   0.7097E+01
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          13    0.5000   0.1410E+01      1.1560      1.1748      0.5716   0.13049E+00   0.54328E+03      0.7817E+01

          14    0.5000   0.1357E+01      1.1560      1.1748      0.5953   0.14493E+00   0.54328E+03      0.8522E+01

          15    0.5000   0.1335E+01      1.1560      1.1748      0.6153   0.15915E+00   0.54328E+03      0.9200E+01

          16    0.5000   0.1293E+01      1.1560      1.1746      0.6326   0.17291E+00   0.54328E+03      0.9868E+01

          17    0.5000   0.1240E+01      1.1560      1.1748      0.6474   0.18611E+00   0.54328E+03      0.1051E+02

          18    0.5000   0.1166E+01      1.1560      1.1748      0.6600   0.19852E+00   0.54328E+03      0.1113E+02

          19    0.5000   0.1081E+01      1.1560      1.1748      0.6708   0.21002E+00   0.54328E+03      0.1172E+02

          20    0.5000   0.9857E+00      1.1560      1.1748      0.6799   0.22051E+00   0.54328E+03      0.1226E+02

          21    0.5000   0.8903E+00      1.1560      1.1748      0.6876   0.22999E+00   0.54328E+03      0.1275E+02

          22    0.5000   0.7207E+00      1.1560      1.1748      0.6938   0.23766E+00   0.54328E+03      0.1320E+02

          23    0.5000   0.5511E+00      1.1560      1.1748      0.6985   0.24353E+00   0.54328E+03      0.1356E+02

          24    0.5000   0.3074E+00      1.1560      1.1748      0.7015   0.24680E+00   0.54328E+03      0.1383E+02



  LOCAL PRESSURE DROP BY SPACER

          Z                  LOCAL COEFF.        LOCAL DP

        0.0                 0.278000E+02       0.802097E+00

         1.6000             0.104000E+01       0.590516E-01

         3.2000             0.104000E+01       0.109034E+00

         4.8000             0.104000E+01       0.170492E+00

         6.4000             0.104000E+01       0.234845E+00

         8.0000             0.104000E+01       0.292282E+00

         9.6000             0.104000E+01       0.354861E+00

        11.2000             0.104000E+01       0.386034E+00

        12.0000             0.140000E+00       0.527136E-01



       TWO-PHASE REGION

                                GRAVITY         FRICTION(COR2PH)            ACCELERATION      TOTAL
       NODE        Z             (PSI)          (PSI)                          (PSI)           (PSI)

          1     0.5000           0.1615         0.0064 (     1.0760)           0.0007         0.1686

          2     1.0000           0.1583         0.0075 (     1.2593)           0.0018         0.1676

          3     1.5000           0.1523         0.0093 (     1.5587)           0.0032         0.1648
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              4    2.0000          0.1429          0.0117 (    1.9680)          0.0045          0.1592

              5    2.5000          0.1330          0.0147 (    2.4644)          0.0056          0.1533

              6    3.0000          0.1228          0.0181 (    3.0266)          0.0065          0.1474

              7    3.5000          0.1132          0.0217 (    3.6337)          0.0072          0.1420

              8    4.0000          0.1044          0.0255 (    4.2747)          0.0077          0.1376

              9    4.5000          0.0971          0.0296 (    4.9612)          0.0086          0.1363

             10    5.0000          0.0897          0.0339 (    5.6818)          0.0089          0.1325

             11    5.5000          0.0836          0.0382 (    6.4055)          0.0090          0.1308

             12    6.0000          0.0784          0.0425 (    7.1249)          0.0092          0.1301

             13    6.5000          0.0740          0.0467 (    7.8265)          0.0090          0.1296

             14    7.0000          0.0703          0.0507 (    8.4928)          0.0087          0.1297

             15    7.5000          0.0672          0.0545 (    9.1292)          0.0086          0.1303

             16    8.0000          0.0646          0.0581 (    9.7406)          0.0084          0.1311

             17    8.5000          0.0623          0.0616 (   10.3212)          0.0082          0.1321

             18    9.0000          0.0603          0.0648 (   10.8656)          0.0078          0.1330

             19    9.5000          0.0587          0.0678 (   11.3683)          0.0074          0.1339

             20   10.0000          0.0573          0.0705 (   11.8261)          0.0068          0.1347

             21   10.5000          0.0561          0.0730 (   12.2381)          0.0063          0.1354

             22   11.0000          0.0551          0.0751 (   12.5891)          0.0052          0.1354

             23   11.5000          0.0544          0.0767 (   12.8650)          0.0040          0.1351

             24   12.0000          0.0539          0.0778 (   13.0501)          0.0022          0.1340

            TOTAL                  2.1713          1.0364                           0.1556          3.3633

            LOCAL LOSS =     1.6593(PSI)
         TOTAL CHANNEL PRESSURE DROP =     5.8247(PSI)


           PARAMETERS FOR THE UPPER PLENUM

                FLOW AREA       LENGTH I       LENGTH II       CURVATURE       HYDR. DIAM.

                254.4000         4.2760         0.8900          2.5820          17.9975

                VOID FRACTION =0.8500E+00VO,UP =0.4755E+01


           PARAMETERS FOR THE RISER
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           LENGTH        FLOW AREA     HYDR.DIAM.         CO            VGJ

           4.8400        42.3000         0.5050          1.1560         1.1748

          GO,R =0.2555E+03     VO,R =0.2860E+02     VOID FRACTION =0.7100E+00
          CORPR =0.1183E+02

       PARAMETERS FOR STEAM SEPARATOR

           INER          LENGTH        LOSS COEF.     FLOW AREA     HYDR. DIAM.

          0.5000E+00     0.7792E+01     0.4121E+01     0.8901E+02     0.5050E+00


       PARAMETERS FOR THE LOOP

            SLOOP          SFLOOP           AA

         0.7000E+00     0.1367E-02      -.1759E-03


       PARAMETERS FOR DOWNCOMER ENTHALPY DYNAMICS

         F.W. ENTH      FLOW AREA      LENGTH            VESSEL TEMPS              PH            HO

         0.4824E+03     0.2968E+03     0.3136E+02     0.5000E+03     0.5170E+03     0.6571E+02     0.3777E+00


                     VESSL WALL
                     THICKNESS(FT)  =   0.5365E+00
                     THERMAL CONDUTIVITY  =   0.2639E-02
                     SPECIFIC HEAT  =   0.1200E+00
                     DENSITY(LB/FT3)  =   0.4980E+03

          WO(LB/S)  =   0.1081E+05         ENTH. MIX.  =   0.5302E+03          ENTH. DC(EXIT)  =   0.5302E+03


       PARAMETERS FOR LOWER PLENUM

         COOLANT MASS(LB) H/T AREA          HO          THICK         HEAT FLUX

         0.1774E+06     0.1238E+03     0.2777E+00     0.6250E+00     0.8254E-01


    DOWNCOMER GEOMETRY

                        LENGTH          FLOW AREA      HYDR. DIAM.      LOSS COEF.

    DOWNCOMER 1       0.5375E+01      0.1565E+03      0.8130E+00       0.0

    DOWNCOMER 2       0.1501E+02      0.2968E+03      0.2841E+01       0.0

    DOWNCOMER 3       0.1635E+02      0.8600E+01      0.7420E+00       0.0


    PRESSURE DROPS (PSI) IN RECIRCULATION LOOP

                        FRICTION        GRAVITY        LOCAL LOSS        TOTAL

    UPPER PLENUM      0.1229E-05      0.3757E+00      0.0               0.3757E+00
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RISER               0.4083E-01        0.4670E+00        0.6507E-01        0.5729E+00

STEAM SEPARATOR     0.7168E-01        0.8200E+00        0.1915E+01        0.2807E+01

DOWNCOMER 1         0.3451E-03       -0.1744E+01        0.0              -0.1744E+01

DOWNCOMER 2         0.3004E-04       -0.4869E+01        0.0              -0.4869E+01

DOWNCOMER 3         0.3682E+00       -0.5306E+01        0.0              -0.4938E+01
EXCLUDING PUMP

PUMP              (PUMP SPEED   0.2000E+02 % RATED)                      -0.8746E+00

LOWER PLENUM        0.3602E-04        0.2844E+01        0.0               0.2844E+01

TOTAL EXTERNAL LOOP PRESSURE DROP                                        -0.5825E+01



VOID COEFFICIENT=  -0.8000E-01     CORE AVERAGE VOID FRACTION=   0.4649E+00     DOPPLER COEFFIENT=  -0.1000E-04


SYSTEM PRESSURE TO DIMENSIONLESS NEUTRON FLUX


      W          MAG(%)        DB        ANGL(DGE)       REAL         IMAG
  0.1256E+00  0.4950E+00 -0.4611E+02  0.2920E+02  0.4321E-02  0.2415E-02
  0.2512E+00  0.7320E+00 -0.4271E+02  0.4145E+02  0.5487E-02  0.4846E-02
  0.3768E+00  0.9475E+00 -0.4047E+02  0.4646E+02  0.6527E-02  0.6868E-02
  0.5024E+00  0.1147E+01 -0.3881E+02  0.4938E+02  0.7467E-02  0.8706E-02
  0.6280E+00  0.1339E+01 -0.3747E+02  0.5120E+02  0.8388E-02  0.1043E-01
  0.7000E+00  0.1451E+01 -0.3677E+02  0.5104E+02  0.9125E-02  0.1128E-01
  0.8000E+00  0.1634E+01 -0.3574E+02  0.5180E+02  0.1010E-01  0.1284E-01
  0.9000E+00  0.1803E+01 -0.3488E+02  0.5166E+02  0.1119E-01  0.1415E-01
  0.1000E+01  0.2012E+01 -0.3393E+02  0.5080E+02  0.1271E-01  0.1559E-01
  0.1256E+01  0.2590E+01 -0.3173E+02  0.4844E+02  0.1718E-01  0.1938E-01
  0.1570E+01  0.3484E+01 -0.2916E+02  0.4212E+02  0.2584E-01  0.2337E-01
  0.1884E+01  0.4678E+01 -0.2660E+02  0.3179E+02  0.3976E-01  0.2464E-01
  0.2198E+01  0.6160E+01 -0.2421E+02  0.1518E+02  0.5945E-01  0.1613E-01
  0.2512E+01  0.7293E+01 -0.2274E+02 -0.8912E+01  0.7205E-01 -0.1130E-01
  0.2650E+01  0.7439E+01 -0.2257E+02 -0.2044E+02  0.6971E-01 -0.2597E-01
  0.2826E+01  0.7066E+01 -0.2302E+02 -0.3454E+02  0.5821E-01 -0.4006E-01
  0.3140E+01  0.5972E+01 -0.2448E+02 -0.5392E+02  0.3517E-01 -0.4827E-01
  0.3454E+01  0.4917E+01 -0.2617E+02 -0.6685E+02  0.1933E-01 -0.4521E-01
  0.3768E+01  0.4111E+01 -0.2772E+02 -0.7602E+02  0.9934E-02 -0.3989E-01
  0.4396E+01  0.3021E+01 -0.3040E+02 -0.8999E+02  0.3498E-05 -0.3021E-01
  0.5024E+01  0.2242E+01 -0.3299E+02 -0.1029E+03 -0.5016E-02 -0.2185E-01
  0.5652E+01  0.1550E+01 -0.3619E+02 -0.1161E+03 -0.6820E-02 -0.1392E-01
  0.6280E+01  0.8970E+00 -0.4094E+02 -0.1280E+03 -0.5520E-02 -0.7070E-02


EXTERNAL REACTIVITY TO DIMENSIONLESS NEUTRON FLUX


      W           MAG          DB        ANGL(DGE)       REAL         IMAG
  0.1256E+00  0.4494E+02  0.3305E+02  0.2059E+02  0.4207E+02  0.1581E+02
  0.2512E+00  0.6059E+02  0.3565E+02  0.3303E+02  0.5080E+02  0.3302E+02
  0.3768E+00  0.7301E+02  0.3727E+02  0.3589E+02  0.5915E+02  0.4280E+02
  0.5024E+00  0.8369E+02  0.3845E+02  0.3594E+02  0.6776E+02  0.4912E+02
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      0.6280E+00  0.9382E+02  0.3945E+02  0.3545E+02  0.7643E+02  0.5441E+02
      0.7000E+00  0.1006E+03  0.4005E+02  0.3576E+02  0.8165E+02  0.5879E+02
      0.8000E+00  0.1066E+03  0.4056E+02  0.3535E+02  0.8697E+02  0.6169E+02
      0.9000E+00  0.1143E+03  0.4116E+02  0.3432E+02  0.9441E+02  0.6445E+02
      0.1000E+01  0.1216E+03  0.4170E+02  0.3420E+02  0.1006E+03  0.6833E+02
      0.1256E+01  0.1367E+03  0.4271E+02  0.3220E+02  0.1157E+03  0.7283E+02
      0.1570E+01  0.1561E+03  0.4387E+02  0.2955E+02  0.1358E+03  0.7698E+02
      0.1884E+01  0.1779E+03  0.4500E+02  0.2620E+02  0.1596E+03  0.7854E+02
      0.2198E+01  0.2039E+03  0.4619E+02  0.2020E+02  0.1913E+03  0.7040E+02
      0.2512E+01  0.2225E+03  0.4695E+02  0.9698E+01  0.2193E+03  0.3748E+02
      0.2650E+01  0.2231E+03  0.4697E+02  0.4561E+01  0.2224E+03  0.1774E+02
      0.2826E+01  0.2147E+03  0.4664E+02 -0.1451E+01  0.2146E+03 -0.5438E+01
      0.3140E+01  0.1930E+03  0.4571E+02 -0.7718E+01  0.1912E+03 -0.2592E+02
      0.3454E+01  0.1752E+03  0.4487E+02 -0.9749E+01  0.1726E+03 -0.2966E+02
      0.3768E+01  0.1636E+03  0.4427E+02 -0.9925E+01  0.1611E+03 -0.2820E+02
      0.4396E+01  0.1516E+03  0.4361E+02 -0.8929E+01  0.1497E+03 -0.2352E+02
      0.5024E+01  0.1462E+03  0.4330E+02 -0.7955E+01  0.1448E+03 -0.2024E+02
      0.5652E+01  0.1436E+03  0.4314E+02 -0.7364E+01  0.1424E+03 -0.1840E+02
      0.6280E+01  0.1420E+03  0.4305E+02 -0.7112E+01  0.1409E+03 -0.1758E+02


    TOTAL REACTIVITY TO NEGATIVE FEEDBACK REACTIVITY


          W           MAG          DB       ANGL(DGE)      REAL         IMAG
      0.1256E+00  0.5689E+01  0.1510E+02 -0.6707E+02  0.2216E+01 -0.5240E+01
      0.2512E+00  0.3151E+01  0.9968E+01 -0.7983E+02  0.5562E+00 -0.3101E+01
      0.3768E+00  0.2234E+01  0.6982E+01 -0.8420E+02  0.2257E+00 -0.2223E+01
      0.5024E+00  0.1749E+01  0.4857E+01 -0.8649E+02  0.1071E+00 -0.1746E+01
      0.6280E+00  0.1441E+01  0.3176E+01 -0.8908E+02  0.2307E-01 -0.1441E+01
      0.7000E+00  0.1308E+01  0.2329E+01 -0.9196E+02 -0.4474E-01 -0.1307E+01
      0.8000E+00  0.1185E+01  0.1474E+01 -0.9395E+02 -0.8171E-01 -0.1182E+01
      0.9000E+00  0.1061E+01  0.5106E+00 -0.9645E+02 -0.1190E+00 -0.1054E+01
      0.1000E+01  0.9775E+00 -0.1974E+00 -0.9980E+02 -0.1665E+00 -0.9633E+00
      0.1256E+01  0.8178E+00 -0.1747E+01 -0.1061E+03 -0.2266E+00 -0.7858E+00
      0.1570E+01  0.6881E+00 -0.3247E+01 -0.1151E+03 -0.2920E+00 -0.6230E+00
      0.1884E+01  0.6007E+00 -0.4427E+01 -0.1256E+03 -0.3497E+00 -0.4884E+00
      0.2198E+01  0.5275E+00 -0.5556E+01 -0.1383E+03 -0.3935E+00 -0.3512E+00
      0.2512E+01  0.4485E+00 -0.6964E+01 -0.1527E+03 -0.3984E+00 -0.2061E+00
      0.2650E+01  0.4130E+00 -0.7682E+01 -0.1590E+03 -0.3856E+00 -0.1477E+00
      0.2826E+01  0.3608E+00 -0.8855E+01 -0.1668E+03 -0.3513E+00 -0.8218E-01
      0.3140E+01  0.2771E+00 -0.1115E+02 -0.1787E+03 -0.2771E+00 -0.6488E-02
      0.3454E+01  0.2095E+00 -0.1358E+02  0.1729E+03 -0.2079E+00  0.2598E-01
      0.3768E+01  0.1595E+00 -0.1595E+02  0.1674E+03 -0.1557E+00  0.3471E-01
      0.4396E+01  0.9864E-01 -0.2012E+02  0.1631E+03 -0.9437E-01  0.2871E-01
      0.5024E+01  0.6834E-01 -0.2331E+02  0.1639E+03 -0.6567E-01  0.1891E-01
      0.5652E+01  0.5343E-01 -0.2544E+02  0.1659E+03 -0.5183E-01  0.1298E-01
      0.6280E+01  0.4545E-01 -0.2685E+02  0.1657E+03 -0.4405E-01  0.1121E-01


    DIMENSIONLESS CORE FLOW TO DIMENSIONLESS NEUTRON FLUX


          W           MAG          DB       ANGL(DGE)      REAL         IMAG
      0.1256E+00  0.6378E+00 -0.3907E+01  0.1629E+02  0.6122E+00  0.1788E+00
      0.2512E+00  0.8567E+00 -0.1343E+01  0.2448E+02  0.7797E+00  0.3550E+00
      0.3768E+00  0.1026E+01  0.2230E+00  0.2309E+02  0.9438E+00  0.4024E+00
      0.5024E+00  0.1166E+01  0.1334E+01  0.1890E+02  0.1103E+01  0.3776E+00
      0.6280E+00  0.1292E+01  0.2228E+01  0.1418E+02  0.1253E+01  0.3166E+00
      0.7000E+00  0.1375E+01  0.2768E+01  0.1208E+02  0.1345E+01  0.2878E+00
```

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   0.8000E+00  0.1440E+01  0.3168E+01  0.8327E+01  0.1425E+01  0.2086E+00
   0.9000E+00  0.1523E+01  0.3654E+01  0.3983E+01  0.1519E+01  0.1058E+00
   0.1000E+01  0.1595E+01  0.4057E+01  0.5634E+00  0.1595E+01  0.1569E-01
   0.1256E+01  0.1712E+01  0.4670E+01 -0.9755E+01  0.1687E+01 -0.2901E+00
   0.1570E+01  0.1820E+01  0.5201E+01 -0.2231E+02  0.1684E+01 -0.6909E+00
   0.1884E+01  0.1902E+01  0.5582E+01 -0.3516E+02  0.1555E+01 -0.1095E+01
   0.2198E+01  0.1967E+01  0.5874E+01 -0.5014E+02  0.1260E+01 -0.1510E+01
   0.2512E+01  0.1907E+01  0.5606E+01 -0.6905E+02  0.6818E+00 -0.1781E+01
   0.2650E+01  0.1806E+01  0.5133E+01 -0.7765E+02  0.3861E+00 -0.1764E+01
   0.2826E+01  0.1608E+01  0.4124E+01 -0.8784E+02  0.6061E-01 -0.1607E+01
   0.3140E+01  0.1243E+01  0.1890E+01 -0.1007E+03 -0.2311E+00 -0.1221E+01
   0.3454E+01  0.9578E+00 -0.3741E+00 -0.1081E+03 -0.2976E+00 -0.9104E+00
   0.3768E+01  0.7520E+00 -0.2476E+01 -0.1121E+03 -0.2833E+00 -0.6965E+00
   0.4396E+01  0.4894E+00 -0.6207E+01 -0.1133E+03 -0.1935E+00 -0.4495E+00
   0.5024E+01  0.3549E+00 -0.8998E+01 -0.1067E+03 -0.1018E+00 -0.3400E+00
   0.5652E+01  0.3054E+00 -0.1030E+02 -0.9761E+02 -0.4043E-01 -0.3027E+00
   0.6280E+01  0.2960E+00 -0.1058E+02 -0.9316E+02 -0.1634E-01 -0.2955E+00


 TOTAL CORE FLOW TO NEGATIVE FEEDBACK CORE FLOW


       W           MAG          DB        ANGL(DGE)      REAL         IMAG
   0.1256E+00  0.5566E+00 -0.5089E+01  0.1207E+02  0.5443E+00  0.1164E+00
   0.2512E+00  0.5180E+00 -0.5714E+01 -0.9689E+01  0.5106E+00 -0.8717E-01
   0.3768E+00  0.4751E+00 -0.6464E+01 -0.2144E+02  0.4423E+00 -0.1737E+00
   0.5024E+00  0.4371E+00 -0.7188E+01 -0.2976E+02  0.3795E+00 -0.2169E+00
   0.6280E+00  0.4103E+00 -0.7737E+01 -0.3654E+02  0.3297E+00 -0.2443E+00
   0.7000E+00  0.4072E+00 -0.7804E+01 -0.4013E+02  0.3113E+00 -0.2625E+00
   0.8000E+00  0.3915E+00 -0.8146E+01 -0.4367E+02  0.2832E+00 -0.2703E+00
   0.9000E+00  0.3813E+00 -0.8375E+01 -0.4851E+02  0.2526E+00 -0.2856E+00
   0.1000E+01  0.3813E+00 -0.8376E+01 -0.5244E+02  0.2324E+00 -0.3022E+00
   0.1256E+01  0.3737E+00 -0.8550E+01 -0.6272E+02  0.1713E+00 -0.3321E+00
   0.1570E+01  0.3766E+00 -0.8482E+01 -0.7872E+02  0.7365E-01 -0.3694E+00
   0.1884E+01  0.3728E+00 -0.8570E+01 -0.9815E+02 -0.5287E-01 -0.3691E+00
   0.2198E+01  0.3489E+00 -0.9145E+01 -0.1205E+03 -0.1770E+00 -0.3007E+00
   0.2512E+01  0.2991E+00 -0.1048E+02 -0.1441E+03 -0.2422E+00 -0.1755E+00
   0.2650E+01  0.2724E+00 -0.1130E+02 -0.1541E+03 -0.2449E+00 -0.1192E+00
   0.2826E+01  0.2321E+00 -0.1269E+02 -0.1662E+03 -0.2254E+00 -0.5534E-01
   0.3140E+01  0.1666E+00 -0.1556E+02  0.1756E+03 -0.1661E+00  0.1279E-01
   0.3454E+01  0.1151E+00 -0.1877E+02  0.1626E+03 -0.1099E+00  0.3444E-01
   0.3768E+01  0.7919E-01 -0.2203E+02  0.1546E+03 -0.7153E-01  0.3397E-01
   0.4396E+01  0.4031E-01 -0.2789E+02  0.1511E+03 -0.3528E-01  0.1949E-01
   0.5024E+01  0.2496E-01 -0.3205E+02  0.1583E+03 -0.2319E-01  0.9225E-02
   0.5652E+01  0.1942E-01 -0.3423E+02  0.1664E+03 -0.1888E-01  0.4565E-02
   0.6280E+01  0.1702E-01 -0.3538E+02  0.1684E+03 -0.1667E-01  0.3413E-02


 DIMENSIONLESS POWER DENSITY TO DIMENSIONLESS CORE FLOW


       W           MAG          DB        ANGL(DGE)      REAL         IMAG
   0.1256E+00  0.5589E+00 -0.5053E+01  0.1715E+03 -0.5527E+00  0.8288E-01
   0.2512E+00  0.3963E+00 -0.8040E+01  0.1491E+03 -0.3402E+00  0.2033E+00
   0.3768E+00  0.3162E+00 -0.1000E+02  0.1423E+03 -0.2503E+00  0.1932E+00
   0.5024E+00  0.2663E+00 -0.1149E+02  0.1403E+03 -0.2048E+00  0.1701E+00
   0.6280E+00  0.2329E+00 -0.1266E+02  0.1397E+03 -0.1776E+00  0.1507E+00
   0.7000E+00  0.2196E+00 -0.1317E+02  0.1391E+03 -0.1660E+00  0.1437E+00
   0.8000E+00  0.2056E+00 -0.1374E+02  0.1399E+03 -0.1572E+00  0.1324E+00
   0.9000E+00  0.1932E+00 -0.1428E+02  0.1404E+03 -0.1488E+00  0.1233E+00
```

```
      0.1000E+01  0.1868E+00 -0.1457E+02  0.1408E+03 -0.1447E+00  0.1181E+00
      0.1256E+01  0.1778E+00 -0.1500E+02  0.1429E+03 -0.1418E+00  0.1073E+00
      0.1570E+01  0.1808E+00 -0.1486E+02  0.1426E+03 -0.1435E+00  0.1099E+00
      0.1884E+01  0.1913E+00 -0.1437E+02  0.1383E+03 -0.1428E+00  0.1273E+00
      0.2198E+01  0.2008E+00 -0.1394E+02  0.1297E+03 -0.1284E+00  0.1544E+00
      0.2512E+01  0.2000E+00 -0.1398E+02  0.1180E+03 -0.9396E-01  0.1765E+00
      0.2650E+01  0.1957E+00 -0.1417E+02  0.1126E+03 -0.7509E-01  0.1807E+00
      0.2826E+01  0.1844E+00 -0.1469E+02  0.1057E+03 -0.4995E-01  0.1775E+00
      0.3140E+01  0.1594E+00 -0.1595E+02  0.9544E+02 -0.1510E-01  0.1587E+00
      0.3454E+01  0.1338E+00 -0.1747E+02  0.8848E+02  0.3549E-02  0.1338E+00
      0.3768E+01  0.1124E+00 -0.1898E+02  0.8464E+02  0.1050E-01  0.1119E+00
      0.4396E+01  0.8466E-01 -0.2145E+02  0.8322E+02  0.9997E-02  0.8407E-01
      0.5024E+01  0.7141E-01 -0.2293E+02  0.8444E+02  0.6919E-02  0.7107E-01
      0.5652E+01  0.6430E-01 -0.2384E+02  0.8375E+02  0.7003E-02  0.6392E-01
      0.6280E+01  0.5800E-01 -0.2473E+02  0.8140E+02  0.8677E-02  0.5735E-01



    *** REACTOR NEUTRONICS INCLUDED ***


    AVERAGE CHANNEL INLET FLOW TO CHANNEL SINGLE PHASE PRESSURE DROP


          W           MAG         DB         ANGL(DGE)        REAL         IMAG
      0.1256E+00  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.2512E+00  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.3768E+00  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.5024E+00  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.6280E+00  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.7000E+00  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.8000E+00  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.9000E+00  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.1000E+01  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.1256E+01  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.1570E+01  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.1884E+01  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.2198E+01  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.2512E+01  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.2650E+01  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.2826E+01  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.3140E+01  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.3454E+01  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.3768E+01  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.4396E+01  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.5024E+01  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.5652E+01  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0
      0.6280E+01  0.6707E+00 -0.3470E+01  0.0            0.6707E+00  0.0


    AVERAGE CHANNEL INLET FLOW TO CHANNEL TWO-PHASE PRESSURE DROP


          W           MAG          DB        ANGL(DGE)       REAL         IMAG
      0.1256E+00  0.2073E+01  0.6333E+01 -0.3139E+01  0.2070E+01 -0.1135E+00
      0.2512E+00  0.2018E+01  0.6097E+01 -0.6186E+01  0.2006E+01 -0.2174E+00
      0.3768E+00  0.1977E+01  0.5919E+01 -0.9540E+01  0.1949E+01 -0.3276E+00
      0.5024E+00  0.1958E+01  0.5837E+01 -0.1300E+02  0.1908E+01 -0.4406E+00
      0.6280E+00  0.1955E+01  0.5823E+01 -0.1627E+02  0.1877E+01 -0.5477E+00
      0.7000E+00  0.1940E+01  0.5758E+01 -0.1757E+02  0.1850E+01 -0.5859E+00
```

```
   0.8000E+00  0.1922E+01  0.5677E+01 -0.2090E+02  0.1796E+01 -0.6857E+00
   0.9000E+00  0.1914E+01  0.5640E+01 -0.2358E+02  0.1754E+01 -0.7658E+00
   0.1000E+01  0.1869E+01  0.5434E+01 -0.2658E+02  0.1672E+01 -0.8364E+00
   0.1256E+01  0.1761E+01  0.4914E+01 -0.3565E+02  0.1431E+01 -0.1026E+01
   0.1570E+01  0.1536E+01  0.3728E+01 -0.4663E+02  0.1055E+01 -0.1117E+01
   0.1884E+01  0.1240E+01  0.1872E+01 -0.5679E+02  0.6794E+00 -0.1038E+01
   0.2198E+01  0.9177E+00 -0.7464E+00 -0.6454E+02  0.3945E+00 -0.8285E+00
   0.2512E+01  0.6119E+00 -0.4266E+01 -0.6749E+02  0.2342E+00 -0.5653E+00
   0.2650E+01  0.4950E+00 -0.6108E+01 -0.6693E+02  0.1939E+00 -0.4554E+00
   0.2826E+01  0.3607E+00 -0.8857E+01 -0.5968E+02  0.1821E+00 -0.3114E+00
   0.3140E+01  0.2260E+00 -0.1292E+02 -0.2569E+02  0.2036E+00 -0.9795E-01
   0.3454E+01  0.2750E+00 -0.1121E+02  0.1364E+02  0.2673E+00  0.6488E-01
   0.3768E+01  0.3927E+00 -0.8118E+01  0.2722E+02  0.3492E+00  0.1797E+00
   0.4396E+01  0.5888E+00 -0.4600E+01  0.3014E+02  0.5092E+00  0.2957E+00
   0.5024E+01  0.6949E+00 -0.3162E+01  0.2749E+02  0.6164E+00  0.3207E+00
   0.5652E+01  0.7327E+00 -0.2701E+01  0.2568E+02  0.5604E+00  0.3175E+00
   0.6280E+01  0.7363E+00 -0.2659E+01  0.2627E+02  0.6603E+00  0.3258E+00


 CHANNEL TWO-PHASE PRESSURE DROP / CHANNEL SINGLE PHASE PRESSURE DROP


       W          MAG          DB      ANGL(DGE)       REAL        IMAG
   0.1256E+00  0.3091E+01  0.9803E+01 -0.3139E+01  0.3087E+01 -0.1693E+00
   0.2512E+00  0.3009E+01  0.9567E+01 -0.6186E+01  0.2991E+01 -0.3242E+00
   0.3768E+00  0.2948E+01  0.9389E+01 -0.9540E+01  0.2907E+01 -0.4885E+00
   0.5024E+00  0.2920E+01  0.9307E+01 -0.1300E+02  0.2845E+01 -0.6570E+00
   0.6280E+00  0.2915E+01  0.9293E+01 -0.1627E+02  0.2798E+01 -0.8167E+00
   0.7000E+00  0.2893E+01  0.9228E+01 -0.1757E+02  0.2758E+01 -0.8736E+00
   0.8000E+00  0.2866E+01  0.9147E+01 -0.2090E+02  0.2678E+01 -0.1022E+01
   0.9000E+00  0.2854E+01  0.9110E+01 -0.2358E+02  0.2616E+01 -0.1142E+01
   0.1000E+01  0.2787E+01  0.8904E+01 -0.2658E+02  0.2493E+01 -0.1247E+01
   0.1256E+01  0.2625E+01  0.8384E+01 -0.3565E+02  0.2133E+01 -0.1530E+01
   0.1570E+01  0.2290E+01  0.7198E+01 -0.4663E+02  0.1573E+01 -0.1665E+01
   0.1884E+01  0.1850E+01  0.5342E+01 -0.5679E+02  0.1013E+01 -0.1548E+01
   0.2198E+01  0.1368E+01  0.2724E+01 -0.6454E+02  0.5883E+00 -0.1235E+01
   0.2512E+01  0.9125E+00 -0.7957E+00 -0.6749E+02  0.3493E+00 -0.8430E+00
   0.2650E+01  0.7340E+00 -0.2638E+01 -0.6693E+02  0.2892E+00 -0.6790E+00
   0.2826E+01  0.5378E+00 -0.5387E+01 -0.5968E+02  0.2715E+00 -0.4643E+00
   0.3140E+01  0.3369E+00 -0.9449E+01 -0.2569E+02  0.3036E+00 -0.1461E+00
   0.3454E+01  0.4101E+00 -0.7742E+01  0.1364E+02  0.3985E+00  0.9674E-01
   0.3768E+01  0.5856E+00 -0.4648E+01  0.2722E+02  0.5208E+00  0.2679E+00
   0.4396E+01  0.8780E+00 -0.1130E+01  0.3014E+02  0.7593E+00  0.4409E+00
   0.5024E+01  0.1036E+01  0.3083E+00  0.2749E+02  0.9192E+00  0.4782E+00
   0.5652E+01  0.1093E+01  0.7689E+00  0.2568E+02  0.9847E+00  0.4734E+00
   0.6280E+01  0.1098E+01  0.8115E+00  0.2627E+02  0.9846E+00  0.4859E+00


 AVERAGE CHANNEL INLET FLOW TO LOOP SINGLE PHASE PRESSURE DROP


       W          MAG          DB      ANGL(DGE)       REAL        IMAG
   0.1256E+00  0.1626E+01  0.4220E+01  0.2619E+01  0.1624E+01  0.7428E-01
   0.2512E+00  0.1631E+01  0.4247E+01  0.5227E+01  0.1624E+01  0.1486E+00
   0.3768E+00  0.1639E+01  0.4292E+01  0.7814E+01  0.1624E+01  0.2228E+00
   0.5024E+00  0.1651E+01  0.4354E+01  0.1037E+02  0.1624E+01  0.2971E+00
   0.6280E+00  0.1666E+01  0.4432E+01  0.1288E+02  0.1624E+01  0.3714E+00
   0.7000E+00  0.1676E+01  0.4484E+01  0.1430E+02  0.1624E+01  0.4140E+00
   0.8000E+00  0.1691E+01  0.4565E+01  0.1624E+02  0.1624E+01  0.4731E+00
   0.9000E+00  0.1709E+01  0.4654E+01  0.1815E+02  0.1624E+01  0.5322E+00
```

```
      0.1000E+01  0.1728E+01  0.4752E+01  0.2001E+02  0.1624E+01  0.5914E+00
      0.1256E+01  0.1786E+01  0.5036E+01  0.2458E+02  0.1624E+01  0.7428E+00
      0.1570E+01  0.1871E+01  0.5439E+01  0.2976E+02  0.1624E+01  0.9284E+00
      0.1884E+01  0.1969E+01  0.5886E+01  0.3445E+02  0.1624E+01  0.1114E+01
      0.2198E+01  0.2080E+01  0.6361E+01  0.3868E+02  0.1624E+01  0.1300E+01
      0.2512E+01  0.2201E+01  0.6852E+01  0.4245E+02  0.1624E+01  0.1486E+01
      0.2650E+01  0.2257E+01  0.7069E+01  0.4398E+02  0.1624E+01  0.1567E+01
      0.2826E+01  0.2330E+01  0.7348E+01  0.4582E+02  0.1624E+01  0.1671E+01
      0.3140E+01  0.2467E+01  0.7842E+01  0.4883E+02  0.1624E+01  0.1857E+01
      0.3454E+01  0.2609E+01  0.8331E+01  0.5152E+02  0.1624E+01  0.2043E+01
      0.3768E+01  0.2757E+01  0.8809E+01  0.5392E+02  0.1624E+01  0.2228E+01
      0.4396E+01  0.3065E+01  0.9729E+01  0.5801E+02  0.1624E+01  0.2600E+01
      0.5024E+01  0.3386E+01  0.1059E+02  0.6134E+02  0.1624E+01  0.2971E+01
      0.5652E+01  0.3716E+01  0.1140E+02  0.6409E+02  0.1624E+01  0.3342E+01
      0.6280E+01  0.4053E+01  0.1216E+02  0.6638E+02  0.1624E+01  0.3714E+01


  AVERAGE CHANNEL INLET FLOW TO LOOP TWO-PHASE PRESSURE DROP


           W          MAG          DB      ANGL(DGE)       REAL        IMAG
      0.1256E+00  0.3324E+01  0.1043E+02 -0.5856E+01  0.3307E+01 -0.3392E+00
      0.2512E+00  0.3085E+01  0.9786E+01 -0.1017E+02  0.3037E+01 -0.5448E+00
      0.3768E+00  0.2878E+01  0.9180E+01 -0.1390E+02  0.2793E+01 -0.6913E+00
      0.5024E+00  0.2735E+01  0.8738E+01 -0.1705E+02  0.2615E+01 -0.8016E+00
      0.6280E+00  0.2655E+01  0.8482E+01 -0.1949E+02  0.2503E+01 -0.8861E+00
      0.7000E+00  0.2625E+01  0.8381E+01 -0.2006E+02  0.2465E+01 -0.9001E+00
      0.8000E+00  0.2559E+01  0.8161E+01 -0.2208E+02  0.2371E+01 -0.9620E+00
      0.9000E+00  0.2531E+01  0.8067E+01 -0.2379E+02  0.2316E+01 -0.1021E+01
      0.1000E+01  0.2475E+01  0.7873E+01 -0.2551E+02  0.2234E+01 -0.1066E+01
      0.1256E+01  0.2361E+01  0.7462E+01 -0.3178E+02  0.2007E+01 -0.1243E+01
      0.1570E+01  0.2150E+01  0.6651E+01 -0.4086E+02  0.1626E+01 -0.1407E+01
      0.1884E+01  0.1830E+01  0.5250E+01 -0.5120E+02  0.1147E+01 -0.1426E+01
      0.2198E+01  0.1417E+01  0.3026E+01 -0.6154E+02  0.6751E+00 -0.1246E+01
      0.2512E+01  0.9603E+00 -0.3520E+00 -0.7043E+02  0.3217E+00 -0.9048E+00
      0.2650E+01  0.7667E+00 -0.2307E+01 -0.7411E+02  0.2099E+00 -0.7375E+00
      0.2826E+01  0.5141E+00 -0.5779E+01 -0.7485E+02  0.1343E+00 -0.4963E+00
      0.3140E+01  0.1434E+00 -0.1687E+02 -0.4599E+02  0.9965E-01 -0.1031E+00
      0.3454E+01  0.2816E+00 -0.1101E+02  0.5180E+02  0.1742E+00  0.2213E+00
      0.3768E+01  0.5510E+00 -0.5178E+01  0.5618E+02  0.3066E+00  0.4577E+00
      0.4396E+01  0.9075E+00 -0.8429E+00  0.5004E+02  0.5828E+00  0.6956E+00
      0.5024E+01  0.1061E+01  0.5133E+00  0.4601E+02  0.7368E+00  0.7633E+00
      0.5652E+01  0.1128E+01  0.1048E+01  0.4722E+02  0.7663E+00  0.8280E+00
      0.6280E+01  0.1229E+01  0.1789E+01  0.5113E+02  0.7711E+00  0.9565E+00


  LOOP TWO-PHASE PRESSURE DROP / LOOP SINGLE PHASE PRESSURE DROP


           W          MAG          DB      ANGL(DGE)       REAL        IMAG
      0.1256E+00  0.2045E+01  0.6215E+01 -0.8475E+01  0.2023E+01 -0.3014E+00
      0.2512E+00  0.1892E+01  0.5539E+01 -0.1540E+02  0.1824E+01 -0.5024E+00
      0.3768E+00  0.1756E+01  0.4888E+01 -0.2172E+02  0.1631E+01 -0.6496E+00
      0.5024E+00  0.1657E+01  0.4385E+01 -0.2741E+02  0.1471E+01 -0.7627E+00
      0.6280E+00  0.1594E+01  0.4050E+01 -0.3238E+02  0.1346E+01 -0.8536E+00
      0.7000E+00  0.1566E+01  0.3897E+01 -0.3436E+02  0.1293E+01 -0.8839E+00
      0.8000E+00  0.1513E+01  0.3596E+01 -0.3833E+02  0.1187E+01 -0.9382E+00
      0.9000E+00  0.1481E+01  0.3413E+01 -0.4194E+02  0.1102E+01 -0.9901E+00
      0.1000E+01  0.1432E+01  0.3121E+01 -0.4552E+02  0.1004E+01 -0.1022E+01
      0.1256E+01  0.1322E+01  0.2426E+01 -0.5636E+02  0.7325E+00 -0.1101E+01
      0.1570E+01  0.1150E+01  0.1211E+01 -0.7062E+02  0.3815E+00 -0.1085E+01
      0.1884E+01  0.9294E+00 -0.6358E+00 -0.8565E+02  0.7046E-01 -0.9267E+00
      0.2198E+01  0.6811E+00 -0.3335E+01 -0.1002E+03 -0.1208E+00 -0.6703E+00
      0.2512E+01  0.4363E+00 -0.7204E+01 -0.1129E+03 -0.1697E+00 -0.4020E+00
      0.2650E+01  0.3398E+00 -0.9377E+01 -0.1181E+03 -0.1600E+00 -0.2997E+00
      0.2826E+01  0.2206E+00 -0.1313E+02 -0.1207E+03 -0.1126E+00 -0.1898E+00
      0.3140E+01  0.5814E-01 -0.2471E+02 -0.9482E+02 -0.4886E-02 -0.5794E-01
      0.3454E+01  0.1079E+00 -0.1934E+02  0.2870E+00  0.1079E+00  0.5407E-03
      0.3768E+01  0.1998E+00 -0.1399E+02  0.2264E+01  0.1997E+00  0.7894E-02
      0.4396E+01  0.2961E+00 -0.1057E+02 -0.7969E+01  0.2932E+00 -0.4105E-01
      0.5024E+01  0.3133E+00 -0.1008E+02 -0.1533E+02  0.3022E+00 -0.8283E-01
      0.5652E+01  0.3036E+00 -0.1035E+02 -0.1687E+02  0.2905E+00 -0.8810E-01
      0.6280E+01  0.3031E+00 -0.1037E+02 -0.1526E+02  0.2924E+00 -0.7977E-01



    *** REACTOR NEUTRONICS EXCLUDED ***


    AVERAGE CHANNEL INLET FLOW TO CHANNEL SINGLE PHASE PRESSURE DROP


          W           MAG          DB       ANGL(DGE)       REAL        IMAG
      0.1256E+00  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.2512E+00  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.3768E+00  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.5024E+00  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.6280E+00  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.7000E+00  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.8000E+00  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.9000E+00  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.1000E+01  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.1256E+01  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.1570E+01  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.1884E+01  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.2198E+01  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.2512E+01  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.2650E+01  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.2826E+01  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.3140E+01  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.3454E+01  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.3768E+01  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.4396E+01  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.5024E+01  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.5652E+01  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0
      0.6280E+01  0.6707E+00 -0.3470E+01  0.0          0.6707E+00  0.0


    AVERAGE CHANNEL INLET FLOW TO CHANNEL TWO-PHASE PRESSURE DROP


          W           MAG          DB       ANGL(DGE)       REAL        IMAG
      0.1256E+00  0.1450E+01  0.3230E+01 -0.2339E+01  0.1449E+01 -0.5919E-01
      0.2512E+00  0.1422E+01  0.3058E+01 -0.4929E+01  0.1417E+01 -0.1222E+00
      0.3768E+00  0.1397E+01  0.2901E+01 -0.8125E+01  0.1382E+01 -0.1974E+00
      0.5024E+00  0.1381E+01  0.2802E+01 -0.1133E+02  0.1354E+01 -0.2712E+00
      0.6280E+00  0.1366E+01  0.2712E+01 -0.1396E+02  0.1326E+01 -0.3296E+00
      0.7000E+00  0.1333E+01  0.2497E+01 -0.1459E+02  0.1290E+01 -0.3358E+00
      0.8000E+00  0.1310E+01  0.2343E+01 -0.1752E+02  0.1249E+01 -0.3942E+00
      0.9000E+00  0.1292E+01  0.2226E+01 -0.1876E+02  0.1224E+01 -0.4156E+00
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  0.1000E+01  0.1236E+01  0.1839E+01 -0.2049E+02  0.1158E+01 -0.4326E+00
  0.1256E+01  0.1141E+01  0.1144E+01 -0.2585E+02  0.1027E+01 -0.4973E+00
  0.1570E+01  0.9916E+00 -0.7316E-01 -0.3016E+02  0.8573E+00 -0.4983E+00
  0.1884E+01  0.8321E+00 -0.1597E+01 -0.3251E+02  0.7017E+00 -0.4472E+00
  0.2198E+01  0.6761E+00 -0.3400E+01 -0.3169E+02  0.5753E+00 -0.3551E+00
  0.2512E+01  0.5420E+00 -0.5319E+01 -0.2597E+02  0.4873E+00 -0.2374E+00
  0.2650E+01  0.4926E+00 -0.6150E+01 -0.2223E+02  0.4560E+00 -0.1864E+00
  0.2826E+01  0.4540E+00 -0.6859E+01 -0.1402E+02  0.4405E+00 -0.1100E+00
  0.3140E+01  0.4315E+00 -0.7300E+01  0.1665E+01  0.4313E+00  0.1254E-01
  0.3454E+01  0.4675E+00 -0.6604E+01  0.1477E+02  0.4521E+00  0.1192E+00
  0.3768E+01  0.5330E+00 -0.5466E+01  0.2246E+02  0.4926E+00  0.2036E+00
  0.4396E+01  0.6649E+00 -0.3545E+01  0.2698E+02  0.5925E+00  0.3017E+00
  0.5024E+01  0.7457E+00 -0.2548E+01  0.2620E+02  0.6691E+00  0.3293E+00
  0.5652E+01  0.7740E+00 -0.2226E+01  0.2527E+02  0.6999E+00  0.3304E+00
  0.6280E+01  0.7737E+00 -0.2229E+01  0.2608E+02  0.6949E+00  0.3401E+00


CHANNEL TWO-PHASE PRESSURE DROP / CHANNEL SINGLE PHASE PRESSURE DROP


       W          MAG         DB       ANGL(DGE)      REAL        IMAG
  0.1256E+00  0.2163E+01  0.6700E+01 -0.2339E+01  0.2161E+01 -0.8826E-01
  0.2512E+00  0.2120E+01  0.6529E+01 -0.4929E+01  0.2113E+01 -0.1822E+00
  0.3768E+00  0.2082E+01  0.6371E+01 -0.8125E+01  0.2061E+01 -0.2943E+00
  0.5024E+00  0.2059E+01  0.6272E+01 -0.1133E+02  0.2019E+01 -0.4044E+00
  0.6280E+00  0.2037E+01  0.6182E+01 -0.1396E+02  0.1977E+01 -0.4914E+00
  0.7000E+00  0.1988E+01  0.5967E+01 -0.1459E+02  0.1924E+01 -0.5007E+00
  0.8000E+00  0.1953E+01  0.5813E+01 -0.1752E+02  0.1862E+01 -0.5878E+00
  0.9000E+00  0.1927E+01  0.5697E+01 -0.1876E+02  0.1824E+01 -0.6198E+00
  0.1000E+01  0.1843E+01  0.5310E+01 -0.2049E+02  0.1726E+01 -0.6451E+00
  0.1256E+01  0.1701E+01  0.4614E+01 -0.2585E+02  0.1531E+01 -0.7416E+00
  0.1570E+01  0.1479E+01  0.3397E+01 -0.3017E+02  0.1278E+01 -0.7430E+00
  0.1884E+01  0.1241E+01  0.1873E+01 -0.3251E+02  0.1046E+01 -0.6668E+00
  0.2198E+01  0.1008E+01  0.6969E-01 -0.3169E+02  0.8578E+00 -0.5295E+00
  0.2512E+01  0.8082E+00 -0.1849E+01 -0.2597E+02  0.7266E+00 -0.3539E+00
  0.2650E+01  0.7345E+00 -0.2680E+01 -0.2223E+02  0.6799E+00 -0.2779E+00
  0.2826E+01  0.6770E+00 -0.3389E+01 -0.1402E+02  0.6568E+00 -0.1640E+00
  0.3140E+01  0.6434E+00 -0.3830E+01  0.1665E+01  0.6432E+00  0.1869E-01
  0.3454E+01  0.6971E+00 -0.3134E+01  0.1477E+02  0.6741E+00  0.1777E+00
  0.3768E+01  0.7947E+00 -0.1996E+01  0.2246E+02  0.7345E+00  0.3036E+00
  0.4396E+01  0.9914E+00 -0.7471E-01  0.2698E+02  0.8835E+00  0.4498E+00
  0.5024E+01  0.1112E+01  0.9219E+00  0.2620E+02  0.9977E+00  0.4910E+00
  0.5652E+01  0.1154E+01  0.1244E+01  0.2527E+02  0.1044E+01  0.4927E+00
  0.6280E+01  0.1154E+01  0.1241E+01  0.2608E+02  0.1036E+01  0.5072E+00


AVERAGE CHANNEL INLET FLOW TO LOOP SINGLE PHASE PRESSURE DROP


       W          MAG         DB       ANGL(DGE)      REAL        IMAG
  0.1256E+00  0.1626E+01  0.4220E+01  0.2619E+01  0.1624E+01  0.7428E-01
  0.2512E+00  0.1631E+01  0.4247E+01  0.5227E+01  0.1624E+01  0.1486E+00
  0.3768E+00  0.1639E+01  0.4292E+01  0.7814E+01  0.1624E+01  0.2228E+00
  0.5024E+00  0.1651E+01  0.4354E+01  0.1037E+02  0.1624E+01  0.2971E+00
  0.6280E+00  0.1666E+01  0.4432E+01  0.1288E+02  0.1624E+01  0.3714E+00
  0.7000E+00  0.1676E+01  0.4484E+01  0.1430E+02  0.1624E+01  0.4140E+00
  0.8000E+00  0.1691E+01  0.4565E+01  0.1624E+02  0.1624E+01  0.4731E+00
  0.9000E+00  0.1709E+01  0.4654E+01  0.1815E+02  0.1624E+01  0.5322E+00
  0.1000E+01  0.1728E+01  0.4752E+01  0.2001E+02  0.1624E+01  0.5914E+00
  0.1256E+01  0.1786E+01  0.5036E+01  0.2458E+02  0.1624E+01  0.7428E+00
```

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    0.1570E+01  0.1871E+01  0.5439E+01  0.2976E+02  0.1624E+01  0.9284E+00
    0.1884E+01  0.1969E+01  0.5886E+01  0.3445E+02  0.1624E+01  0.1114E+01
    0.2198E+01  0.2080E+01  0.6361E+01  0.3868E+02  0.1624E+01  0.1300E+01
    0.2512E+01  0.2201E+01  0.6852E+01  0.4245E+02  0.1624E+01  0.1486E+01
    0.2650E+01  0.2257E+01  0.7069E+01  0.4398E+02  0.1624E+01  0.1567E+01
    0.2826E+01  0.2330E+01  0.7348E+01  0.4582E+02  0.1624E+01  0.1671E+01
    0.3140E+01  0.2467E+01  0.7842E+01  0.4883E+02  0.1624E+01  0.1857E+01
    0.3454E+01  0.2609E+01  0.8331E+01  0.5152E+02  0.1624E+01  0.2043E+01
    0.3768E+01  0.2757E+01  0.8809E+01  0.5392E+02  0.1624E+01  0.2228E+01
    0.4396E+01  0.3065E+01  0.9729E+01  0.5801E+02  0.1624E+01  0.2600E+01
    0.5024E+01  0.3386E+01  0.1059E+02  0.6134E+02  0.1624E+01  0.2971E+01
    0.5652E+01  0.3716E+01  0.1140E+02  0.6409E+02  0.1624E+01  0.3342E+01
    0.6280E+01  0.4053E+01  0.1216E+02  0.6638E+02  0.1624E+01  0.3714E+01


  AVERAGE CHANNEL INLET FLOW TO LOOP TWO-PHASE PRESSURE DROP


        W           MAG          DB        ANGL(DGE)       REAL         IMAG
    0.1256E+00  0.1487E+01  0.3446E+01  0.2153E+00  0.1487E+01  0.5588E-02
    0.2512E+00  0.1448E+01  0.3218E+01  0.1110E+01  0.1448E+01  0.2807E-01
    0.3768E+00  0.1429E+01  0.3101E+01  0.3722E+00  0.1429E+01  0.9284E-02
    0.5024E+00  0.1439E+01  0.3161E+01 -0.1141E+01  0.1439E+01 -0.2866E-01
    0.6280E+00  0.1469E+01  0.3343E+01 -0.2403E+01  0.1468E+01 -0.6162E-01
    0.7000E+00  0.1475E+01  0.3377E+01 -0.1771E+01  0.1474E+01 -0.4558E-01
    0.8000E+00  0.1474E+01  0.3371E+01 -0.3810E+01  0.1471E+01 -0.9796E-01
    0.9000E+00  0.1502E+01  0.3535E+01 -0.4642E+01  0.1497E+01 -0.1216E+00
    0.1000E+01  0.1479E+01  0.3400E+01 -0.5464E+01  0.1472E+01 -0.1408E+00
    0.1256E+01  0.1450E+01  0.3225E+01 -0.1051E+02  0.1425E+01 -0.2643E+00
    0.1570E+01  0.1345E+01  0.2575E+01 -0.1596E+02  0.1293E+01 -0.3698E+00
    0.1884E+01  0.1171E+01  0.1369E+01 -0.2078E+02  0.1095E+01 -0.4154E+00
    0.2198E+01  0.9446E+00 -0.4949E+00 -0.2309E+02  0.8689E+00 -0.3705E+00
    0.2512E+01  0.7061E+00 -0.3022E+01 -0.1933E+02  0.6663E+00 -0.2337E+00
    0.2650E+01  0.6082E+00 -0.4319E+01 -0.1512E+02  0.5872E+00 -0.1586E+00
    0.2826E+01  0.5279E+00 -0.5548E+01 -0.3358E+01  0.5270E+00 -0.3093E-01
    0.3140E+01  0.5086E+00 -0.5873E+01  0.2276E+02  0.4690E+00  0.1967E+00
    0.3454E+01  0.6351E+00 -0.3943E+01  0.4010E+02  0.4858E+00  0.4091E+00
    0.3768E+01  0.8012E+00 -0.1925E+01  0.4625E+02  0.5541E+00  0.5788E+00
    0.4396E+01  0.1057E+01  0.4850E+00  0.4639E+02  0.7294E+00  0.7656E+00
    0.5024E+01  0.1170E+01  0.1363E+01  0.4498E+02  0.8276E+00  0.8269E+00
    0.5652E+01  0.1222E+01  0.1740E+01  0.4712E+02  0.8313E+00  0.8953E+00
    0.6280E+01  0.1318E+01  0.2399E+01  0.5110E+02  0.8277E+00  0.1026E+01


  LOOP TWO-PHASE PRESSURE DROP / LOOP SINGLE PHASE PRESSURE DROP


        W           MAG          DB        ANGL(DGE)       REAL         IMAG
    0.1256E+00  0.9148E+00 -0.7738E+00 -0.2404E+01  0.9140E+00 -0.3836E-01
    0.2512E+00  0.8882E+00 -0.1029E+01 -0.4117E+01  0.8860E+00 -0.6376E-01
    0.3768E+00  0.8719E+00 -0.1191E+01 -0.7441E+01  0.8645E+00 -0.1129E+00
    0.5024E+00  0.8717E+00 -0.1193E+01 -0.1151E+02  0.8542E+00 -0.1739E+00
    0.6280E+00  0.8821E+00 -0.1089E+01 -0.1529E+02  0.8509E+00 -0.2326E+00
    0.7000E+00  0.8803E+00 -0.1107E+01 -0.1607E+02  0.8459E+00 -0.2437E+00
    0.8000E+00  0.8716E+00 -0.1194E+01 -0.2005E+02  0.8187E+00 -0.2989E+00
    0.9000E+00  0.8791E+00 -0.1119E+01 -0.2279E+02  0.8105E+00 -0.3405E+00
    0.1000E+01  0.8559E+00 -0.1352E+01 -0.2547E+02  0.7727E+00 -0.3681E+00
    0.1256E+01  0.8118E+00 -0.1811E+01 -0.3509E+02  0.6643E+00 -0.4666E+00
    0.1570E+01  0.7191E+00 -0.2864E+01 -0.4571E+02  0.5021E+00 -0.5148E+00
    0.1884E+01  0.5945E+00 -0.4517E+01 -0.5524E+02  0.3390E+00 -0.4884E+00
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0.2198E+01  0.4541E+00 -0.6856E+01 -0.6177E+02  0.2148E+00 -0.4001E+00
0.2512E+01  0.3208E+00 -0.9874E+01 -0.6178E+02  0.1517E+00 -0.2827E+00
0.2650E+01  0.2695E+00 -0.1139E+02 -0.5910E+02  0.1384E+00 -0.2313E+00
0.2826E+01  0.2266E+00 -0.1290E+02 -0.4918E+02  0.1481E+00 -0.1715E+00
0.3140E+01  0.2062E+00 -0.1372E+02 -0.2607E+02  0.1852E+00 -0.9062E-01
0.3454E+01  0.2434E+00 -0.1227E+02 -0.1142E+02  0.2386E+00 -0.4818E-01
0.3768E+01  0.2906E+00 -0.1073E+02 -0.7668E+01  0.2880E+00 -0.3877E-01
0.4396E+01  0.3450E+00 -0.9244E+01 -0.1162E+02  0.3379E+00 -0.6949E-01
0.5024E+01  0.3455E+00 -0.9230E+01 -0.1636E+02  0.3315E+00 -0.9735E-01
0.5652E+01  0.3288E+00 -0.9662E+01 -0.1696E+02  0.3145E+00 -0.9593E-01
0.6280E+01  0.3252E+00 -0.9757E+01 -0.1528E+02  0.3137E+00 -0.8570E-01



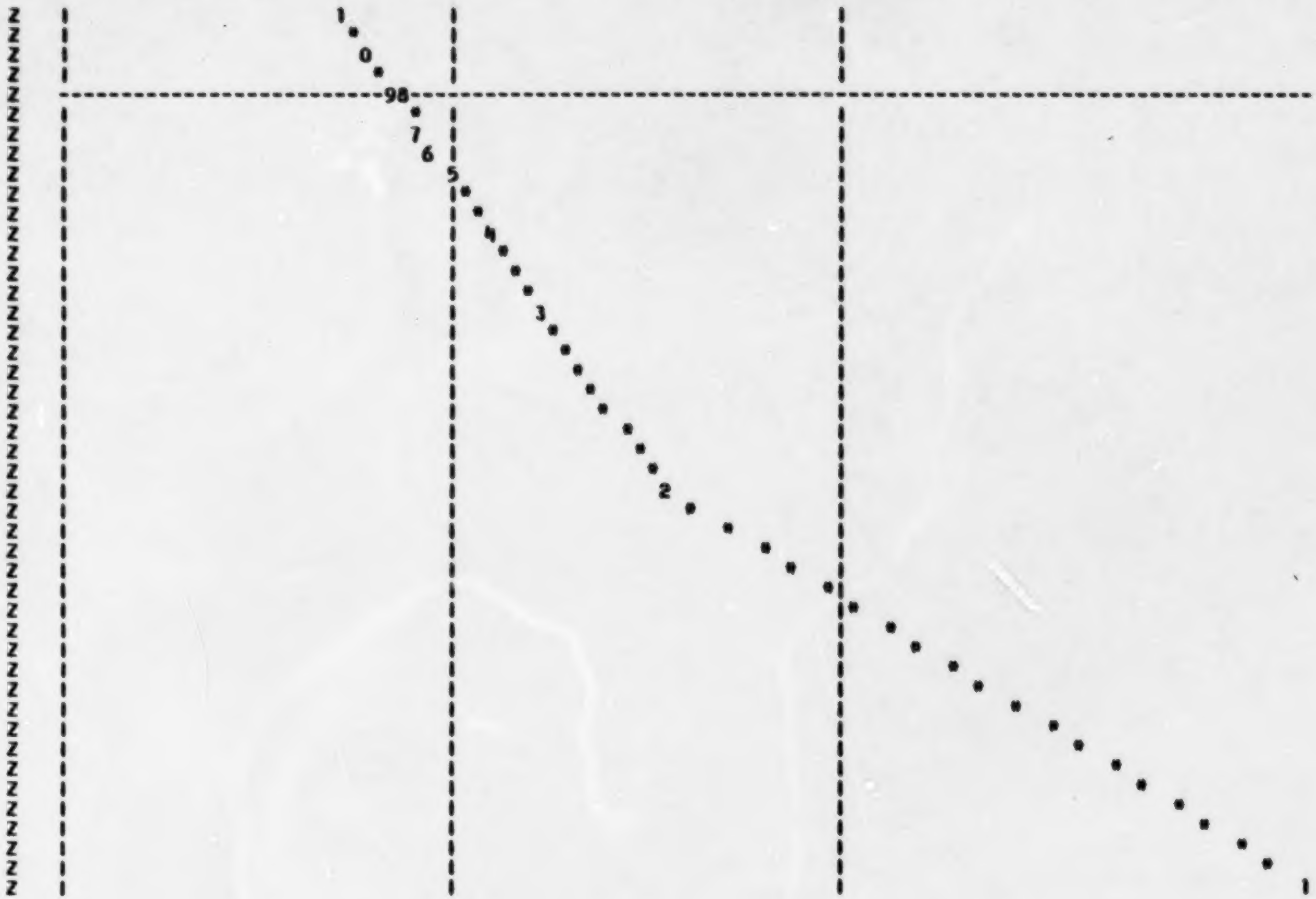
                               NYQUIST PLOT

         PERIOD                       REAL          IMAG          MODULE         ARG

   1 0.5003E+02                 0.222E+01    -0.524E+01    0.569E+01-0.6707E+02
   2 0.2501E+02                 0.556E+00    -0.310E+01    0.315E+01-0.7983E+02
   3 0.1668E+02                 0.226E+00    -0.222E+01    0.223E+01-0.8420E+02
   4 0.1251E+02                 0.107E+00    -0.175E+01    0.175E+01-0.8649E+02
   5 0.1001E+02                 0.231E-01    -0.144E+01    0.144E+01-0.8908E+02
   6 0.8976E+01                -0.447E-01    -0.131E+01    0.131E+01-0.9196E+02
   7 0.7854E+01                -0.817E-01    -0.118E+01    0.118E+01-0.9395E+02
   8 0.6981E+01                -0.119E+00    -0.105E+01    0.106E+01-0.9645E+02
   9 0.6283E+01                -0.166E+00    -0.963E+00    0.978E+00-0.9980E+02
  10 0.5003E+01                -0.227E+00    -0.786E+00    0.818E+00-0.1061E+03
  11 0.4002E+01                -0.292E+00    -0.623E+00    0.688E+00-0.1151E+03
  12 0.3335E+01                -0.350E+00    -0.488E+00    0.601E+00-0.1256E+03
  13 0.2859E+01                -0.394E+00    -0.351E+00    0.527E+00-0.1383E+03
  14 0.2501E+01                -0.398E+00    -0.206E+00    0.449E+00-0.1527E+03
  15 0.2371E+01                -0.386E+00    -0.148E+00    0.413E+00-0.1590E+03
  16 0.2223E+01                -0.351E+00    -0.822E-01    0.361E+00-0.1668E+03
  17 0.2001E+01                -0.277E+00    -0.649E-02    0.277E+00-0.1787E+03
  18 0.1819E+01                -0.208E+00     0.260E-01    0.209E+00 0.1729E+03
  19 0.1668E+01                -0.156E+00     0.347E-01    0.159E+00 0.1674E+03
  20 0.1429E+01                -0.944E-01     0.287E-01    0.986E-01 0.1631E+03
  21 0.1251E+01                -0.657E-01     0.189E-01    0.683E-01 0.1639E+03
  22 0.1112E+01                -0.518E-01     0.130E-01    0.534E-01 0.1659E+03
  23 0.1001E+01                -0.440E-01     0.112E-01    0.455E-01 0.1657E+03



1                                                   NYQUIST DIAGRAM
    -------------------------------------------------------------------------------------------------------SCALE=1.0E+00
Z   I                               I                               I
Z   I                               I                               I
Z   I                               I                               I
Z   I                               I                               I
Z   I                               I                               I
Z   I                               I                               I
Z   I                               I                               I
Z   I                               I                               I
Z   ---------------------8*9*02-------------------------------------------------------------------------
Z   I                   6*7         I                               I
Z   I                  5            I                               I
Z   I                  *            I                               I
Z   I                  3            I                               I
Z   I                   2           I                               I
```



```
SISO STABILITY MARGINS
GAIN  MARGIN =  11.5932 (DB)
PHASE MARGIN =  81.1049 (DEGREE)


MIMO STABILITY MARGINS
GAIN  MARGIN =     0.1915 (DB)
PHASE MARGIN =     1.2769 (DEGREE)

          W           1/SIGMA
```

```
    1081                        0.1256E+00    0.3946E-01
    1082                        0.2512E+00    0.4127E-01
    1083                        0.3768E+00    0.4293E-01
    1084                        0.5024E+00    0.4447E-01
    1085                        0.6280E+00    0.4535E-01
    1086                        0.7000E+00    0.4486E-01
    1087                        0.8000E+00    0.4521E-01
    1088                        0.9000E+00    0.4487E-01
    1089                        0.1000E+01    0.4365E-01
    1090                        0.1256E+01    0.4079E-01
    1091                        0.1570E+01    0.3514E-01
    1092                        0.1884E+01    0.2913E-01
    1093                        0.2198E+01    0.2422E-01
    1094                        0.2512E+01    0.2229E-01
    1095                        0.2650E+01    0.2271E-01
    1096                        0.2826E+01    0.2505E-01
    1097                        0.3140E+01    0.3223E-01
    1098                        0.3454E+01    0.4230E-01
    1099                        0.3768E+01    0.5393E-01
    1100                        0.4396E+01    0.7729E-01
    1101                        0.5024E+01    0.9497E-01
    1102                        0.5652E+01    0.1074E+00
    1103                        0.6280E+01    0.1204E+00
  End of file
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NUFREQ-NP FORTRAN LISTING

PART I

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```
C
C    ***********************************************************
C    *          THERMAL HYDRAULIC PROGRAM SYSTEM IN NUFREQ-NP      *
C    ***********************************************************
C
      REAL KF,LAMBDA(5),K1,LR,KLOSS,MUTL,L1,L2, JOIN
      COMPLEX TAU1,TAU2,RATIO,S,Z1,Z2,Z3,M1,M2,M3,OLDRAT,TSUM2,
     1       OH,PI1,PI2,PI3,GAM1,GAM2,GAM3,ZPKP,STC2,CSTB1,CSTB2,
     2       TG,TB1,TB2,TF,TR1,TR2,HS,STC1,TEE,AAA,U1,FALF,ZPK1
      COMPLEX F11, ZPK, CXJ1,CXJ2,CXJ3, CXA1,CXA2,CXA3
      COMPLEX T,SANI,SAIN,AMN,ANM,RAIR,RAIN,SAKN,SANK,GAMN,TALP1
      COMPLEX RANI,GANM,ZNI,BI,RKI,XZNI,XBM,XRKM,CXK,CXKN
      COMPLEX TZ1,TZ2,TWO,THREE, T1,DPH1, TGAM1,TPI1
      COMPLEX RR1,RR2,RR3, DPUP1,DPUP2,DPUP3, DWSW1,DWSW2,DWSW3
      COMPLEX TH1,TH2,TH3,PWW1, PWW2,PDWSW2,DWSW5,DPCORE,DPCORS
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMPLEX GAM4,STC3,STC4,STC5,STC6,PP,TALP4,TLP4,TALP2,TALP3
     1         ,DGAMP,RR4,CLTX,ALSUM1,ALSUM2,TLP
     @         ,PI4,PM4,DWSW4,SH1,SH2,SH3,SH4,H2KP
      COMPLEX PPS,CKI42S,SKI4S,CW,OMEGA,STOM,ZP,CSBX3
      COMPLEX CXJ4,CXA4,TCP,TLOOP4,VPL,TH4,DPUP4
      COMPLEX GPI1,GPI2,GPI3,GPI4,QL1,QL2,QL3,QL4,QL2S,QL3S,QL4S,
     @        VJ1,VJ2,VJ3,WW1,WW2,WW1S,WW2S,HIN1S,HIN2S
      COMPLEX RATIOP,RATIOK,OPTK,OPTH,OPTJ,PTOJ,RATIOW,WC2P,OPTS
      COMPLEX PUP1,PUP2,PUP3,PUP4,PR1,PR2,PR3P,PR4,PR3
      COMPLEX XK,XKP,XKRA,XKPRA,Y1,Y2,XIL,U1P,U2,U2S,U3,U4,ZPD
      COMPLEX SW1,SW2,SW3,SW4,PST1,PST2,PST3,PST4,
     @        SRHO1,SRHO2,SRHO3,
     @        SRHO4,TRANSP,SJ1,SJ2,SJ3,SJ4,FW,FR,FRS,FJ,H,WH
      COMPLEX PKJ,PKQ,PKH,PKP,PHJ1,SHJ,SHW
      COMPLEX CCS,PLS,GLS,PIC,FPIC
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      NAMELIST/THM/TH1,TH2,TH3,TH4
      DIMENSION VEL3D(5),RPWR(5),A(4,4),U(4,4),V(4,4),SV(4),WORK(4)
      DIMENSION XREA(100),YIMA(100), PER(100), AMOD(100), ARGU(100)
      DIMENSION COMM1(20),COMM2(20),COMM3(20),COMM4(20),COMM5(20),
     1    COMM6(20),COMM7(20),COMM8(20),COMM9(20),COMM10(20),
     2    COMM13(20), COMMEN(20),WW(100),AMAG(100),WH(2,50,2,3)
      DIMENSION CPS(100), PHASE(100), VMAG(100),SVMAX(50)
      COMMON/A/ STF(50),CLMP(2,50),CLDBP(2,50),CLAP(2,50),
     @   CLIP(2,50),CLMK(2,50),CLDBK(2,50),CLAK(2,50),
     @   CLIK(2,50),OPMK(2,50),OPDBK(2,50),OPAK(2,50),
     @   OPIK(2,50),OPMJ(2,50),OPDBJ(2,50),OPAJ(2,50),
     @   OPIJ(2,50),OPMH(2,50),OPDBH(2,50),OPAH(2,50),
     @   OPIH(2,50),PJM(2,50),PJDB(2,50),PJA(2,50),
     @   PJI(2,50),CLRP(2,50),CLRK(2,50),OPRK(2,50),
     @   OPRJ(2,50),OPRH(2,50),PJR(2,50),
     @   TMP(2,50),TDBP(2,50),TAP(2,50),TRP(2,50),TIP(2,50),
     @   DPM(2,50),DPDB(2,50),DPA(2,50),DPR(2,50),DPI(2,50),
     @   SPM(2,50),SPDB(2,50),SPA(2,50),SPR(2,50),SPI(2,50),
     @   CLMW(2,50),CLDBW(2,50),CLAW(2,50),CLIW(2,50),CLRW(2,50),
     @   OPMS(2,50),OPDBS(2,50),OPAS(2,50),OPIS(2,50),OPRS(2,50),
     @   PIM(2,50),PIDB(2,50),PIA(2,50),PIR(2,50),PII(2,50)
C
      COMMON/OPTION/ IOSUB, IOHW, IO2Q, IPILO, ISLIP, IRW
      COMMON/CONST1/ C1(5),C2(5),C3(5),C4,C5(5),C8(5,30),
     1       C9(5,30),C18(5), C21(5), C22(5),C25(5),
     2       C26(5), 16, V7(5), DD1, CK1, CMP
      COMMON /CONSUB/ CSB2(5,30),CSB3(5,30),CSB4(5,30),
     1       CSB5(5,30),CSB6(5,30),CSB7(5,30),CSB8(5,30),
     2       CSB9(5,30),CSB10(5,30),CSBQ(5,30),CSBD(5,30),
     3       CSBE(5,30),CSBF(5,30), CSBG(5,30),CSBX1(5),
     4       CSBX2(5)
      COMMON/CONST2/ P,VCH,VIN(5),AXS(5),DH(5),DHIN(5),
     1       PH(5),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2       DENSF,VFG1,RHOG,GO(5),GO2(5),HO(5),GC,G1,KLOSS(30),
     3       FRICMO(5),VGJH(5,30),COH(5,30),CZERO,VGJ,DPTS,
     4       GO2RF(5),HFG1,ZSP(30),NUMBSP(5,30),ALHEAT,CXF(5),
     5       AVEQ,CHOMO1,CHOMO2,XKIN(5),XKEXIT(5)
C
      COMMON/CONSS1/ QDIS(5,30), QO(5,30), DZ(5,30),Z(5,30),
     1       K1(5,30), CKIN(5,30), ZETA(5,30), DOIN(5,30),
     2       DOOUT(5,30), ALPIN(5,30),BEE(5,30), CPI1(5,30),
     3       COR2PH(5,30), ZETSP(5,30), WIN
      COMMON/PCHOUT/XCHOUT(5), ACHOUT(5), CCHOUT(5)
      COMMON /DIM1/ DELX, DELZ, CHLAMB(5), ALFNOD(5,30),
     1              BBLAMB(5)
      COMMON/CONSS2/ NTOT(5),NBB(5),NBB1(5),NSP,N1PSP(5),
     1               K2PSP(5), NDP(5), NDP1(5), ISUB(5)
      COMMON /DPCON1/GAM1(5),GAM2(5,30),GAM3(5), PI1(5),
     1               PI2(5,30),PI3(5), TALP1(5,30),
     2               TSUM2(5,30),TAU1(5),TAU2(5),TALP3(5,30)
      COMMON /PERT/ DELVI, DELQO, DELK,DELP
      COMMON /CONWD1/ CPH,TKH,DENSH,CPC,TKC,DENSC,CRS,CRI,CRO,
     1                GAPC, V22(5,30), THICKH
      COMMON /WD2/Z1, Z2, Z3(30)
      COMMON /CPBOIL/ M1, M2, M3, TH1,TH2,TH3, HS(30),PH4,TH4
      COMMON /PBOIL/ CONBB
      COMMON /DPCON3/ ST2(30)
      COMMON /DPCON2/ STC1(30), STC(5,30), CSTB1(30), CSTB2(30),
     1                STC2(30)
      COMMON /CMP2/TG(11,30),TB1(4,30),TB2(4,30),TF(19,30),
     1       TR1(12,30),TR2(12,30)
C
      COMMON /RISER/ COR,VGJR,CKRO,RL,AR,DRIN,DR,PI,CL1,CL2,CL3,CL4,
     1       CL5, CL6, CR5, CR6, UPJ1(5), UPJ2(5), RO11, RO12,
     2               RO21, RO22, XROUT, UPJIN
      COMMON /CLOOP/ SLOOP, SFLOOP, RLOOP,AA,
     @               VL1(5), VL2(5), VL3(5), DPLPT,RATW
      COMMON /CUPPER/RKIN,RKEXIT,AP,RPO,RP1,RP2,CL10(5),CL11(5),
     1                CLT,AXSCH,RAR,AD,DL,DHDL,FDL, F1(5),F2(5),
     2                RJ1(5),RJ2(5),RJ3(5),F3(5)
      COMMON /CDELH1/ HFW, ADC, PHV, DKV, CPV, DENV, TEMV, TEMINV,
     1                THV, HOD, PLM, AHLP, THLP, HOLP, WO, DLENG
      COMMON /CDELH2/ CH1, CH2, CH3, CH4, CH5, CH7, CH8, CH9, CH10
      COMMON /CXCH/ CXJ1(5),CXJ2(5,30),CXJ3(5), CXA1(5),
     1              CXA2(5,30),CXA3(5)
      COMMON /CXLP/ RR1(5), RR2, RR3, DPUP1(5), DPUP2, DPUP3,
     1              DWSW1(5),DWSW2(5,30),DWSW3,T1,DPH1,DPUP4
      COMMON /CGHT/ F11
      COMMON /RESULT/XZ, SS1, SS2
      COMMON/SIM1/IMAX,JMAX,KMAX,ICASE,ISPEC,JSPEC,INUCLR,XKEFF
      COMMON/PTKO/ZPK, ZPK1, ZPKP,DRDU, VOCAL
      COMMON/VOIDPT/FALF(5,30),U1(5),TGAM1(5),TPI1(5)
      COMMON/WSW5/DWSW5
      COMMON/DPP/DPCORE,DPCORS
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPFPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMMON/COREP/ STC3(30),STC4(30),STC5(30),STC6(30),PP(30),
     1              TALP2(5,30,30),TALP4(5,30),TLP4,PJ
```

```
      COMMON/DELTAP/DGAMP,DRHOG,DHF,DHG,DCZERO,DVGJ,DCOR,DVGJR
      COMMON/RISERP/CLTX,RR4,CRP5,CRP6,RO13,RO23,CL12,UPJ3,ALPRO,
     1            CGR,RHOR,VRO,CRCON,UPALP
      COMMON/YPUP/PUP1(5),PUP2(5,30),PUP3,PUP4
      COMMON/YPR/PR1(5),PR2(5,30),PR3,PR3P,PR4
      COMMON/PTK2/ZPD
      COMMON/SUBP/YSTAR(5,30),ENHTP
      COMMON/SUBPP/PVGH(5,30)
      COMMON/SWITCP/IDCZC,IDVGJC,IDCZR,IDVGJR
      COMMON/STABP/TLP,DWSW4
      COMMON/PPQQ/GAMA(5),PI4(5)
      COMMON/PWD/ZP(30)
      COMMON/PSP/CSBX3(5,30),ALOUT(5,30)
      COMMON/PCON2P/PPS(30)
      COMMON/PDQ/CW(7),OMEGA(4,30),STOM(4)
      COMMON/PXX/PXEXT(5,30)
      COMMON/YYY/ZLUP,FLUP,GOU,DHUP,ROUP,FUP,ZLR,FLR,ROR,FRR
     @          ,ADLP,DHLP,ZLLP,FLLP,XKLP,GOLP,FLP
     @          ,AD1,DH1,ZL1,FL1,XK1,GO1,FD1
     @          ,AD2,DH2,ZL2,FL2,XK2,GOD2,FD2
     @          ,AD3,DH3,ZL3,FL3,XK3,GO3,FD3
     @          ,SPUMP,CPUMP
      COMMON/SEPA/XINER,XLSEP,XKSEP,XASEP,XRHOS,ALPSEP,GOSEP,
     @            YLSEP,DHSEP,FSEP,CSEP,VSEP,CORPR
      COMMON/CSEPA/SW1(5),SW2(5,30),SW3,SW4,PST1(5),PST2(5,30),
     @             PST3,PST4,SRHO1(5),SRHO2(5,30),SRHO3,SRHO4,
     @             SJ1(5),SJ2(5,30),SJ3,SJ4
      COMMON/DSEPA/FW,FR,FRS,FJ
      COMMON/SDOM/WC2P,AD1P,TURB,WTURB,ADOME,VDOME
      COMMON/PIV/IV
      COMMON/PGAM/IGAM,IDRF
      COMMON/QQQ/Q3D(5,30)
      COMMON/WKM/XWK,XWM
      COMMON/KEY/THO,IKEY
      COMMON/PCO/ICO
      COMMON/SBHP/B4K(5,30),B5K(5,30),BTEMO(5,30),AVGX(5,30)
      COMMON/PCXCH/CXJ4(5),CXA4(5)
      COMMON/RNEW/F3P,RJ3P
      COMMON/PPERT/TCP(5),TLOOP4(5)
C     COMMON/HLP/PHL(5,30),EPSUB(5,30)
      COMMON/YCYS/TCS
      COMMON/HLDY/SH1,SH2,SH3,SH4
      COMMON/HLDZ/H2KP(30)
C     COMMON/YV/YV1IN,YV2IN,YV3IN,YV4IN,YV1OT,YV2OT,YV3OT,YV4OT
      COMMON/CFSUB/CF(5,30),CG(5,30)
      COMMON/PWF/PWFIN(10),PWINT(10),PWMULT(10)
      COMMON/MULT/NN(5)
      COMMON/MULTW/UPJW(5),CLW(5),PJOUT(5)
      COMMON/SSS/GPI1(5),GPI2(5,30),GPI3(5),GPI4(5),
     @QL1(5),QL2(5,30),QL3,QL4,QL2S(5,30),QL3S(5),QL4S(5),
     @  VJ1(5),VJ2(5),VJ3(5),WW1(5),WW2,WW1S(5,5),
     @           WW2S(5),HIN1S(5),HIN2S
      COMMON/VEL/VELD(5)
      COMMON/TF/RATIOP,RATIOK,OPTK,OPTH,RATIOW,OPTJ,PTOJ,TRANSP,
     @          OPTS
      COMMON/PBB/POWER,BYPOWF,BYFLWF
      COMMON/SKIN/XK(5,30,5,30),XKP(5,30),XKRA(10,10),XKPRA(10)
      COMMON/GKIN/IKIN,IDCHTY(15,15),ITY(225),JJMX(15),JJD8(15,15),
     @            ITY8(150)
      COMMON/DPLER1/Y1,Y2
      COMMON/DPLER2/U1P(5,30),U2(5,30),U2S(5,30),U3(5,30),U4(5,30),
     @                XIL(5,30)
      COMMON/WET/EW(30)
      COMMON/MIMO/II(2,3)
      COMMON/POINTK/PKJ,PKQ,PKH,PKP,PHJ1,SHJ,SHW
      COMMON/PHASOR/GCS(2),PLS(2),GLS(2),PIC(2)
C   QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C     ********    FORMAT    ******************************
C
    1 FORMAT(20A4)
    2 FORMAT(8I4)
    3 FORMAT(8F10.4)
    4 FORMAT(6E10.4)
    5 FORMAT(2E12.6)
    6 FORMAT(2E15.5)
    7 FORMAT(///10X,'*****    POWER-TO-VOID TRANSFER FUNCTION    *****')
    8 FORMAT(///10X, '@@@  OPEN-LOOP TRANSFER FUNCTION AT  Z = ',
     1        2X,F8.2 ,2X,'@@@' )
    9 FORMAT(/12X,'CPS',17X, 'GH',22X,'MAG',18X,'PHASE')
   10 FORMAT(1HO, 43H***** EXIT QUALITY OUTSIDE LIMITS, XEXIT =  , F6.2)
   12 FORMAT(/// 46H **** NO FORCING FUNCTION WAS SPECIFIED *****'     )
   13 FORMAT(8X,F9.5,3X,2(2X,E10.4),5X,E10.4,5X,E10.4)
   15 FORMAT(///, 32X, 'NYQUIST PLOT' //
     1 11X,'PERIOD',19X,4HREAL,10X,4HIMAG,9X,'MODULE',8X,'ARG' //
     2        (I6, E11.4, 12X, 3E14.3, E11.4 ))
   16 FORMAT(///,1H1, 50X, 16HNYQUIST DIAGRAM     )
   17 FORMAT(///15X,'SISO STABILITY MARGINS',/15X,
     1        'GAIN  MARGIN =',F9.4,' (DB)',/15X,
     @        'PHASE MARGIN =',F9.4,' (DEGREE)')
   18 FORMAT(1X,'STABILITY MARGIN'/,F10.4,' (DB)')
   19 FORMAT(2X,'ICASE = ',I3)
   20 FORMAT(///15X,'*** SYSTEM IS UNSTABLE  ***')
  202 FORMAT(///15X,'*** STABILITY MARGINS ARE NOT CALCULATED ***'/
     @       ,15X,'*** DUE TO INADEQUQTE FREQUENCY POINTS ***')
   21 FORMAT(10X,'**RATIO = **',2(5X,E12.6))
   31 FORMAT(1H1, 25X, 20A4 //)
   33 FORMAT(1H1,//////5X,'***** SINGLE NODE ANALYSIS *****')
   34 FORMAT(//1X, 18HSYSTEM PARAMETERS   //
     1        5X,30H P = SYSTEM PRESSURE (PSIA) = , F9.2  /
     2        5X,35H TIN = INLET TEMPERATURE (DEG-F) = , F9.2 /
     3        5X, 'SATURATION TEMPERATURE CORRESPONDING TO P (F) = '
     4        , F9.2 /
     5        5X,'ACTIVE FUEL (HEATER) LENGTH (FT) = ', F9.4/
     6        5X,'CORE AVERAGE VOLUMETRIC HEAT  =',E12.6//
     7        5X,'TOTAL NUMBER OF CHANNELS  = ',I5/
     8        5X,'TOTAL NUMBER OF NODES IN CHANNEL = ', I4)
   35 FORMAT(//,'FREQUENCY',/5X,'INITIAL FREQ.  =',F9.6/
     1    5X,'FINAL FREQ.     =',F9.6/5X,'FREQ. INTERVAL  =',F9.6)
   36 FORMAT(//,'OPTION', /5X,'IOSUB  =',I4/5X,'IOHW  =',I4/
     1       5X,'IO2Q  =', I4/5X,'IK  =',I4/5X,'ISI  =',I4/
     2       5X,'IREG =', I4/5X,'IBODE=',I4)
   37 FORMAT(///,'EXTERNAL PERTURBATION')
   38 FORMAT(/5X,'** DELVI   =  ',F9.3, '**' )
   39 FORMAT(/5X,'** DELQO   =  ',F9.3, '**' )
   41 FORMAT(/5X,'** DELDP   =  ',F9.3, '**' )
   42 FORMAT(/5X,'** DELK    =  ',F9.3, '**' )
   54 FORMAT(//13X, '**  THE B.B. OF CORE-AVERAGED CHANNEL  =',
     1        2X,F12.6,2X, '(FT)  **')
   60 FORMAT(/// 46H **** NO FORCING FUNCTION HAS SPECIFIED *****
   61 FORMAT(/10X, '**********  NODE-AVERAGED VOID FRACTION',
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     1          2X,'***********')
   62 FORMAT(/15X, 6(5X,E10.4) )
   63 FORMAT(//10X, 'NODE    =',3X,I3)
   64 FORMAT(////11H FREQUENCY=,E10.3,5HRAD/S, 10X,7HPERIOD=,E10.3,3HSEC,
     1      5X, 8H(MULT.= , F7.4, 1H), I40)
   65 FORMAT(/5X,'FREQUENCY',5X,'MAGNITUTE')
   66 FORMAT(/5X,'FREQUENCY',9X,'PHASE')
   70 FORMAT(//10X, '**** ITERATION FOR FLOW REDISTRIBUTION DIVERGE'
     1            ,' ****',/15X,'PRESS. DROP ITERATION =',I4,
     2            /15X,'FLOW RATE ITERATION =',I4)
   71 FORMAT(//3X, '3) PRESSURE DROP ACROSS THE CORE  =', 2X,F10.4,
     1       //3X, '4) PRESSURE DROP IN THE LOOP    =', 2X,F10.4,
     2       ///3X, 'TOTAL PRESSURE DROP IN THE WHOLE LOOP',
     3       ' (PUMP HEAD)  =', 2X,F10.4 )
C
C    *********    INPUT    ****************************
      READ(5,1) COMMEN
C
      READ(5,1) COMM1
      READ(5,1) COMM9
      READ(5,2) ICASE, ISPEC, JSPEC, IRUN, ICAL
      IF(IRUN .EQ. 0) GO TO 2000
C
      READ(5,2) NCH, NODES, NSP
C    * OPTION
      READ(5,1) COMM2
      READ(5,2) IOSUB, IOHW, IO2Q, IK, ISI, IREG, IBODE, IPRINT
      READ(5,2) IPILO, ISLIP, IRW
C    * POWER, BYPOWF, BYFLWF
      READ(5,1) COMM8
      READ(5,4)POWER,BYPOWF,BYFLWF
C    * SYSTEM(CORE) PARAMETER
      READ(5,1) COMM3
      READ(5,4) P, TIN, ALHEAT, TSATP, AVEQ
C    * PARAMETERS FOR FLOW REDISTRIBUTION
      IF(IRW .EQ. 0) GO TO 100
      READ(5,4) DPGS, WIN
C    * CHANNEL COMMON PARAMETERS
  100 READ(5,1) COMM5
      READ(5,4) CZERO, VGJ, DELX, DELZ, CHOMO1, CHOMO2
      READ(5,4) CKI, CMP
C    * LOCAL LOSS COEFFICIENT
      IF(NSP .EQ. 0)GO TO 3333
      READ(5,1) COMM10
      DO 101 N=1,NSP
      READ(5,5) ZSP(N), KLOSS(N)
  101 CONTINUE
C
 3333 IF(ICAL .LE. 1) GO TO 110
      IF(ICAL .EQ. 4) GO TO 110
C
C    * FOR THE LOOP ANALYSIS
C
C       1) UPPER PLENUM
      READ(5,1) COMM13
      READ(5,4) AXSCH, AP, RAR, RPO, RP1, RP2
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      READ(5,3) ZLUP,FLUP
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQuQQQQQQ
C       2) RISER
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      READ(5,1) COMM13
      READ(5,4) COR, VGJR, RL, AR, DRIN, RKIN, RKEXIT
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      READ(5,3) ZLR,FLR
C       3) STEAM SEPARATOR
      READ(5,1) COMM13
      READ(5,3) XINER,XLSEP,XKSEP,XASEP,YLSEP,DHSEP,CSEP
C       4) STEAM DOME
      READ(5,1) COMM13
      READ(5,4) ADOME,VDOME,TURB
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C       5) LOOP
      READ(5,1) COMM13
      READ(5,4) SLOOP, SFLOOP, AA, AD, DL, DHDL, WO, RATW
C
      IF(ICAL .NE. 3) GO TO 110
C
C       6) DOWNCOMER
      READ(5,1) COMM13
      READ(5,4) HFW, ADC, PHV, DKV, CPV, DENV, TEMV, TEMINV, THV,
     1           HOD, DLENG
C
      HOD=HOD/3600.
C       7) LOWER PLENUM
      READ(5,1) COMM13
      READ(5,4) PLM, AHLP, THLP, HOLP
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
  110 READ(5,3) ADLP,DHLP,ZLLP,FLLP,XKLP
C       8) DOWNCOMER D1
      READ(5,3) AD1,DH1,ZL1,FL1,XK1
C       9) DOWNCOMER D2
      READ(5,3) AD2,DH2,ZL2,FL2,XK2
C      10) DOWNCOMER D3
      READ(5,3) AD3,DH3,ZL3,FL3,XK3
C      11) PUMP
      READ(5,333) IPUMP,SPUMP
  333 FORMAT(I4,F10.0)
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      HOLP=HOLP/3600.
      AVEQ=AVEQ/3600.
      WO=WO*1.0E+06/3600.
      IF(IRW .EQ. 0)GO TO 102
      WIN=WIN*1.0E+06/3600.
  102 CONTINUE
      NCH1 =  1
C
      KMAX=NODES
C
C    * CHANNEL PARAMETRS
      READ(5,1) COMM4
C
      JLL=1
      READ(5,2)JRR
      JR=JRR
      DO 121 J=JLL,JRR
      READ(5,2)NN(J)
      READ(5,4) VEL3D(J),PH(J),AXS(J),DHIN(J),CXF(J),XKIN(J),
     1            XKEXIT(J),RPWR(J)
        READ(5,1) COMM4
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        KNOD = 0
  122   KNOD1 = KNOD + 1
        KNOD5 = KNOD + 5
        READ(5,4) (Q3D(J,I), I=KNOD1,KNOD5)
        KNOD = KNOD + 5
      IF(KNOD .LT. NODES) GO TO 122
  121 CONTINUE
C      * PERTURBATION PARAMETER & FREQUNCY
      READ(5,1) COMM6
      READ(5,4) DELVI,DELQO,DELK,DELP
      IF(DELP .EQ. 0.)GO TO 11
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C  READ IN SWITCHES; 1=USE DERIVITE, 0=NOT USED
      READ(5,2) IDCZC,IDVGJC,IDCZR,IDVGJR
      READ(5,2) IDRHOG,IDHF,IDHG
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
   11 CONTINUE
      READ(5,40)IWC
   40 FORMAT(I4)
      READ(5,44)(PWFIN(I),PWINT(I),PWMULT(I),I=1,IWC)
   44 FORMAT(3F10.0)
C      * PARAMETERS FOR HEATED WALL DYNAMICS
      READ(5,1) COMM7
      IF(IOHW .EQ. 1) GO TO 130
      IF(IOHW .EQ. 2) GO TO 131
      IF(IOHW .EQ. 3) GO TO 132
      IF(IOHW .EQ. 4) GO TO 133
  130 READ(5,4) CPH, DENSH
      GO TO 134
  131 READ(5,4) CPH, TKH, DENSH, THICKH
      GO TO 134
  132 READ(5,4) CPH, TKH, DENSH, CRI, CRO
      GO TO 134
  133 READ(5,4) CPH,TKH,DENSH, CPC,TKC,DENSC, CRS,CRI,CRO, GAPC
      GAPC=GAPC/3600.
  134 CONTINUE
C
C
C   **************    PRINT  INPUT  PARAMETER   ************************
C
      WRITE(6,31) COMMEN
      READ(5,49)ICE,CKCAAL,IV,ICVGJ,IKEY,IDRF,XWK,XWM
   49 FORMAT(I4,F10.0,I4,I4,I4,I4,2F10.5)
      READ(5,2)ICO,ISOS,IW,IPX,IENT,IRSLIP
      READ(5,48) IVOCAL,PCAPLA,DOP
   48 FORMAT(I4,4F10.0)
      WRITE(6,499)IV,ICVGJ,IKEY,IDRF,XWK,XWM
  499 FORMAT('LOOP OPTION IV= ',I2,2X,'ICVGJ = ',
     @ I2,2X,'IKEY= ',I2,2X,'IDRF= ',I2,2X,'XWK,XWM= ',2(F10.5,2X))
      WRITE(6,151)ICO,ISOS,IW,IPX,IENT,IRSLIP,IVOCAL
  151 FORMAT('ICO= ',I2,2X,'ISOS= ',I2,2X,'IW=',I2,2X,'IPX=',I2,2X,
     @      'IENT=',I2,2X,'IRSLIP= ',I2,2X,'IVOCAL= ',I2)
      WRITE(6,173)PCAPLA,DOP
  173 FORMAT('NEUTRON LIFETIME(SEC)= ',E10.4,5X,
     @      'DOPPLER COEF.= ',E10.4,5X)
      WRITE(6,175)POWER,BYPOWF,BYFLWF
  175 FORMAT(//,'POWER = ',E10.4,' MWT',/2X,
     @      'BYPASS POWER FRACTION = ',E10.4,2X,
     @      'BYPASS FLOW FRACTION= ',E10.4)
      POWER=POWER*1.0E+06*3.4137/3600.
```

```
C
      IF(NODES .EQ. 1) WRITE(6,33)
      WRITE(6,34) P, TIN, TSATP, ALHEAT, AVEQ, NCH, NODES
      WRITE(6,36) IOSUB, IOHW, IO2Q, IK, ISI, IREG, IBODE
C
      WRITE(6,37)
      IF((DELVI+DELQO+DELK+DELP) .LE. 0.0) GO TO 6000
      IF(DELVI .NE. 0.) WRITE(6,38) DELVI
      IF(DELQO .NE. 0.) WRITE(6,39) DELQO
      IF(DELK .NE. 0.) WRITE(6,42) DELK
      IF(DELP .NE. 0.) WRITE(6,41) DELP
C
      G1 = 32.17
      GC = 32.17*144.
      PI = 3.141592654
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C J=778.158 LBF-FT/BTU
      PJ=778.158/144.
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      IWIT = 0
      KIP1 = 0
      KIP2 = 0
      MSPEC = 0
      SUMA=0.
      EPS1 = 1.0E-02
      IF(IRW .EQ. 0)GO TO 95
      EPS2 = WIN*1.0E-02
   95 CONTINUE
  301 DO 340 I=JLL,JRR
  300 VCH=VEL3D(I)
      DO 315 J=1,NODES
      DZ(I,J)=DELZ
      QDIS(I,J)=Q3D(I,J)*AVEQ*RPWR(I)
  315 CONTINUE
      ICH = 0
      IF(IRW .EQ. 0) GO TO 316
      IF(IRW .EQ. 1 .AND. IWIT .LE. 1) GO TO 325
  316 ICH = IPRINT
C
C    * CALCULATE CONSTANTS WHICH ARE INDEP'T ON NODES
C
  325 CALL CONSS(I,ICH,ICAL,IWIT)
      IF(ISLIP .EQ. 0 .AND. ICVGJ .NE. 0)GO TO 311
      GO TO 411
  311 CZERO=1.2-0.2*SQRT(RHOG/DENSF)
      TAVE=(TIN+TSATP)/2.
      SIGMA=SGMA(P,TAVE)
      VGJ=2.9*(C4*SIGMA*G1*32.2/DENSF**2)**0.25
  411 CONTINUE
      IF(DELP .EQ. 0)GO TO 412
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C IF SWITCH IS OFF SET DERIVITE TO ZERO
      IF(IDRHOG .EQ. 0)DRHOG=0.0
      IF(IDHF.EQ. 0) DHF=0.0
      IF (IDHG .EQ. 0)DHG=0.0
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
C    * CALCULATE STEADY-STATE NODE QUANTITIES & PRESSURE DROPS
C
```

```
C
  412 CALL STEADY(NODES, I, ICH, ICAL, IWIT,CHALF,RPWR)
       IF (IRW .EQ. 0)SUMA=SUMA+CHALF*NN(I)
      IF(IWIT .LT. 2)GO TO 53
      SUMA=SUMA+CHALF*NN(I)
   53 CONTINUE
C
C    * FLOW REDISTRIBUTION WITH CONSTANT PRESSURE DROP B.C. FOR
C        EACH CHANNEL
C       DPTS ; CALCULATED TOTAL PRESSURE DROP IN THE CHANNEL
C       DPGS ; EXPECTED CONSTANT PRESSURE DROP THROUGH ALL CHANNEL
C       EPS1 ; CONVERGENCE CRITERION
C
       IF(IRW .EQ. 0) GO TO 335
       IF(IWIT .EQ. 2) GO TO 335
      RDPCH = (DPTS-DPGS) / DPGS
       IF(ABS(RDPCH) .LE. EPS1) GO TO 330
       VEE = DPGS/DPTS
       VEL3D(I) = SQRT(VEE)*VEL3D(I)
       WRITE(6,82)I,KIP1,DPGS,DPTS,VEL3D(I)
   82  FORMAT(//'CHANNEL TYPE,KIP1,DPGS,DPTS,VIN',2X,I2,2X,I4,2X,
     @        3(E13.6,2X))
       KIP1 = KIP1 + 1
       IF(KIP1 .GT. 30) GO TO 4000
       IWIT = 1
       GO TO 300
C
  330  IWIT = 0
       KIP1 = 0
       GO TO 340
  335 IF((XCHOUT(I).GT.1.0) .OR. (XCHOUT(I).LE.0.0)) GO TO 5000
  340 CONTINUE
      VFCORE=SUMA/FLOAT(NCH)
C
C    * APPLY ANOTHER B.C ; WIN = SUM OF WI
C       WIN ; CORE TOTAL INLET FLOW RATEEXCLUDING BYPASS FLOW
C       WI  ; CHANNEL INLET FLOW RATE
       IF(IRW .EQ. 0) GO TO 355
       IF(IWIT .EQ. 2) GO TO 355
       WSUM = 0.
       DO 345 J=JLL,JRR
       WSUM = WSUM + VIN(J)*AXS(J)*DENSI*NN(J)
  345  CONTINUE
       IF(ABS(WIN-WSUM) .LE. EPS2) GO TO 350
       DPGS = DPGS*(1.+(SQRT(WIN)-SQRT(WSUM))/SQRT(WIN))
       WRITE(6,84)KIP2,DPGS,DPTS,(VIN(I),I=JLL,JRR),WSUM
   84  FORMAT('KIP2,DPGS,DPTS,VIN,WSUM',2X,I4,2X,8(E13.6,2X))
       KIP2 = KIP2 + 1
       IF(KIP2 .GT. 30) GO TO 4000
       GO TO 301
  350  IWIT = 2
       GO TO 301
C
  355 DO 370 J=JLL,JRR
      IF(ISUB(J) .GT. 0) GO TO 360
      LAMBDA(J) = CHLAMB(J)
      GO TO 370
  360 LAMBDA(J) = 0.
  370 CONTINUE
      DO 426 I=JLL,JRR
  426 VELD(I)=VEL3D(I)
C
C
C
      JL1=JLL
      JR1=JR
C
C    * CALCULATE THE S.S PARAMETERS OF THE LOOP
C
      DPLPT = 0.
      IF(IRW .EQ. 1) GO TO 393
      WOSUM = 0.
      DO 392 I=JLL,JRR
      WOSUM = WOSUM + AXS(I)*GO(I)*NN(I)
  392 CONTINUE
      WIN = WOSUM
      DPGS = DPTS
  393 IF(ICAL .LE. 1) GO TO 391
      CALL XLOOP(ICAL, JLL, JRR,IPUMP,IRSLIP)
  391 CONTINUE
C
C
C
C   $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C     . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C    *  CALCULATE EACH PERTURBATION CORRESPONDING TO FREQUENCY
C     . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C
      IF(ICAL.EQ.0) GO TO 2000
      IX=0
      IY=0
      ICOUNT = 1
      IF(IREG .GE. 1) ICOUNT = 0
   55 IX=IX+1
      IF(IX .GT. IWC)GO TO 600
      WMULT=PWMULT(IX)
      WINT=PWINT(IX)
      WFIN=PWFIN(IX)
      IF(WINT .GT. WFIN)GO TO 600
      WMUL=WMULT
      ISIG=ISI-1
      SIG = 10.0**(-ISI)
      SIGP1 = 1.0 + SIG
      OLDW=0.0
      RATIO = CMPLX(0.,0.)
C
      W1=WINT
      OLDW = 100000.0
      GO TO 415
  410 CONTINUE
      IF(IREG.EQ.2) W1=W1+WMUL
      IF(IREG.NE.2) W1=W1*WMUL
  415 IF(W1.GT.WFIN .AND. IX .LE. IWC)GO TO 55
      PERIOD = 2.0*PI/W1
      IF(IREG .GE. 1) GO TO 420
      OLDRAT = RATIO
      NPER=INT(ALOG10(PERIOD))
      IF(PERIOD.LE.1.0)ISIG=ISI
      PERIOD=AINT(10.**ISIG*PERIOD/(10.**NPER))*10.**(NPER-ISIG)
      W1 = 2.0*PI/PERIOD
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      IF(ABS(OLDW-W1)/OLDW.LE.10.0**(-ISI)) GO TO 410
  420 S=CMPLX(0.,W1)
C
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C CALCULATE D(GAMA)/DP
      DGAMP=(S/PJ-DENSF*(1-ALPRO)*S*DHF-
     @       RHOG*ALPRO*S*DHG)/HFG1
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      IF(IREG .GE. 1) GO TO 425
      IF(OLDW .GT. W1)  GO TO 430
  425 ICOUNT = ICOUNT + 1
      IY=IY+1
      IF(ICOUNT .GT. 100) GO TO 600
  430 CONTINUE
      WW(ICOUNT)=W1
C
      DO 460 K=JL1,JR1
C
C    ***   CALCULATE THE WALL DYNAMICS   ***
C
      IF(IOHW .EQ. 0) GO TO 445
         CALL WALLDY(S, K)
  445 CONTINUE
C
C    ***   CALCULATE THE BOILING BOUNDARY PERTURBATION   ***
C
      IF(ISUB(K) .GT. 0) GO TO 450
      XSBJ = 0.
      IF(IOSUB .EQ. 1) XSBJ = CSBX2(K)
         CALL DELBB(S, LAMBDA(K), K, XSBJ)
      GO TO 455
  450    M1 = CMPLX(0.,0.)
         M2 = CMPLX(0.,0.)
         M3 = CMPLX(0.,0.)
         PM4=CMPLX(0.,0.)
         SH1=CMPLX(0.,0.)
         SH2=CMPLX(0.,0.)
         SH3=CMPLX(1.,0.)
         SH4=CMPLX(0.,0.)
         TH1=CMPLX(0.,0.)
         TH2=CMPLX(0.,0.)
         TH3=CMPLX(1.,0.)
         TH4=CMPLX(0.,0.)
      NP1X=NTOT(K)
      DO 456 IXK=1,NP1X
      XIL(K,IXK)=CMPLX(0.,0.)
      U1P(K,IXK)=CMPLX(0.,0.)
      U2(K,IXK)=CMPLX(0.,0.)
      U2S(K,IXK)=CMPLX(0.,0.)
      U3(K,IXK)=CMPLX(0.,0.)
  456 U4(K,IXK)=CMPLX(0.,0.)
      NTSX=NDP1(K)
      DO 457 IYK=NTSX,NP1X
      U2S(K,IYK)=Y1*Z3(IYK)+Y2
  457 U4(K,IYK)=Y1*ZP(IYK)
C
C    ***  CALCULATE THE TOTAL PRESSURE DROP IN THE SINGLE- & THE TWO
C                PHASE REGION   ***
C
C    * CALCULATION OF CONSTANTS FOR PRESSURE DROP PERTURBATION
```

```
C
  455    CALL CON2DP(S, K)
         NP1=NTOT(K)
         DO 56 IP=1,NP1
         TALP1(K,IP)=CMPLX(0.,0.)
         TALP3(K,IP)=CMPLX(0.,0.)
         TALP4(K,IP)=CMPLX(0.,0.)
         DO 571 IPP=1,IP
  571    TALP2(K,IP,IPP)=CMPLX(0.,0.)
   56    CONTINUE
         CALL DPPERT(S, LAMBDA(K), K, ICAL,IPX,IENT)
  460 CONTINUE

     * CALCULATE PRESSURE DROP PERTURBATION FOR THE LOOP
C
      DO 462 K=JLL,JRR
      NP1=NTOT(K)
      RR1(K) = CMPLX(0.,0.)
      DWSW1(K) = CMPLX(0.,0.)
      DPUP1(K) = CMPLX(0.,0.)
      U1(K)=CMPLX(0.,0.)
      DO 92 IP=1,NP1
      DWSW2(K,IP)=CMPLX(0.,0.)
      FALF(K,IP)=CMPLX(0.,0.)
   92 CONTINUE
  462 CONTINUE
      RR2 = CMPLX(0.,0.)
      RR3 = CMPLX(0.,0.)
      DPUP2 = CMPLX(0.,0.)
      DPUP3 = CMPLX(0.,0.)
      DWSW3 = CMPLX(0.,0.)
      T1 = CMPLX(0.,0.)
      DPH1 = CMPLX(0.,0.)
      IF(ICAL .LE. 1) GO TO 461
      CALL DPLP(ICAL,JL1,JR1,S,ICASE)
C
  461 CONTINUE
C
C
C    ***   CALCULATE NEUTRON POINT KINETICS TRANSFER FUNCTION   ***
C
      ZPK = CMPLX(0.0,0.0)
      ZPKP= CMPLX(0.0,0.0)
      IF(ISOS .EQ. 0)GO TO 701
      CALL POINT(S,VFCORE,ICE,CKCAAL,PCAPLA,DOP)
      VOCAL=CKCAAL
  701 GO TO 480
C
   58 FORMAT(8(E13.6,1X))
C
C     . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C    *  CALCULATE TRANSFER FUNCTIONS
C     . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C
  480 LL=0
  848 LL=LL+1
      LMAX=1
C     IF LMAX=2 PARALLEL CHANNEL OSCILLATION IS CONSIDERED
      IF(LL .GT. LMAX)GO TO 777
      CALL TPDP(ICAL,JLL,JRR,LL)
```

203

```
      DO 290 K=JLL,JRR
      NP1=NTOT(K)
      DWSW1(K)=CMPLX(0.,0.)
      DO 292 IP=1,NP1
  292 DWSW2(K,IP)=CMPLX(0.,0.)
  290 CONTINUE
      DWSW3=CMPLX(0.,0.)
      DWSW4=CMPLX(0.,0.)
      DWSW5=S*SLOOP/GC+WO*SFLOOP/(DENSI*GC)-AA
       IF(LL .GE. 2) GO TO 487
      CALL STABTY(S,IK,RATIO,AMRAT,ARRAT,NCH1,ICOUNT,IBODE,IW,JLL,
     @             JRR,ICASE)
       IF(LL .GE. 2 .OR. IK .EQ. 0)GO TO 487
      WRITE(99,58)PKJ,PKQ,PKH,PKP,PHJ1,SHJ,SHW
      WRITE(99,58)(U1(ICHL),ICHL=JLL,JRR)
      DO 182 ICHL=JLL,JRR
  182 WRITE(99,58)(FALF(ICHL,K),K=1,KMAX)
      WRITE(99,58)(XKPRA(ICHL),ICHL=JLL,JRR)
      DO 184 ICHL=JLL,JRR
  184 WRITE(99,58)(XKP(ICHL,K),K=1,KMAX)
      DO 186 ICHL1=JLL,JRR
  186 WRITE(99,58)(XKRA(ICHL1,ICHL2),ICHL2=JLL,JRR)
      DO 188 IC1=JLL,JRR
      DO 190 JK1=1,KMAX
      WRITE(99,58)((XK(IC1,JK1,IC2,JK2),JK2=1,KMAX),IC2=JLL,JRR)
  190 CONTINUE
  188 CONTINUE
  487 CONTINUE
C
      STF(IY)=AIMAG(S)
      CLMP(LL,IY)=CABS(RATIOP)*100.
      XLMP=CABS(RATIOP)
      CLDBP(LL,IY)=20.*ALOG10(XLMP)
      CLAP(LL,IY)=ANGL(RATIOP)
      CLRP(LL,IY)=REAL(RATIOP)
      CLIP(LL,IY)=AIMAG(RATIOP)
      CLMK(LL,IY)=CABS(RATIOK)
      XLMK=CABS(RATIOK)
      CLDBK(LL,IY)=20.*ALOG10(XLMK)
      CLAK(LL,IY)=ANGL(RATIOK)
      CLRK(LL,IY)=REAL(RATIOK)
      CLIK(LL,IY)=AIMAG(RATIOK)
      OPMK(LL,IY)=CABS(OPTK)
      OPDBK(LL,IY)=20.*ALOG10(OPMK(LL,IY))
      OPAK(LL,IY)=ANGL(OPTK)
      OPRK(LL,IY)=REAL(OPTK)
      OPIK(LL,IY)=AIMAG(OPTK)
      CLMW(LL,IY)=CABS(RATIOW)
      XLMW=CABS(RATIOW)
      CLDBW(LL,IY)=20.*ALOG10(XLMW)
      CLAW(LL,IY)=ANGL(RATIOW)
      CLRW(LL,IY)=REAL(RATIOW)
      CLIW(LL,IY)=AIMAG(RATIOW)
      OPMJ(LL,IY)=CABS(OPTJ)
      OPDBJ(LL,IY)=20.*ALOG10(OPMJ(LL,IY))
      OPAJ(LL,IY)=ANGL(OPTJ)
      OPRJ(LL,IY)=REAL(OPTJ)
      OPIJ(LL,IY)=AIMAG(OPTJ)
      PJM(LL,IY)=CABS(PTOJ)
      PJDB(LL,IY)=20.*ALOG10(PJM(LL,IY))
      PJA(LL,IY)=ANGL(PTOJ)
      PJR(LL,IY)=REAL(PTOJ)
      PJI(LL,IY)=AIMAG(PTOJ)
      DO 610 LL=1,2
      FPIC=PIC(LL)
      DPCORE=GCS(LL)
      DPCORS=PLS(LL)
      TRANSP=GLS(LL)
      OPTH=PIC(LL)/GCS(LL)
      OPTS=PLS(LL)/GLS(LL)
      DPM(LL,IY)=CABS(DPCORE)
      DPDB(LL,IY)=20.*ALOG10(DPM(LL,IY))
      DPA(LL,IY)=ANGL(DPCORE)
      DPR(LL,IY)=REAL(DPCORE)
      DPI(LL,IY)=AIMAG(DPCORE)
      PIM(LL,IY)=CABS(FPIC)
      PIDB(LL,IY)=20.*ALOG10(PIM(LL,IY))
      PIA(LL,IY)=ANGL(FPIC)
      PIR(LL,IY)=REAL(FPIC)
      PII(LL,IY)=AIMAG(FPIC)
      SPM(LL,IY)=CABS(DPCORS)
      SPDB(LL,IY)=20.*ALOG10(SPM(LL,IY))
      SPA(LL,IY)=ANGL(DPCORS)
      SPR(LL,IY)=REAL(DPCORS)
      SPI(LL,IY)=AIMAG(DPCORS)
      TMP(LL,IY)=CABS(TRANSP)
      XLMP=CABS(TRANSP)
      TDBP(LL,IY)=20.*ALOG10(XLMP)
      TAP(LL,IY)=ANGL(TRANSP)
      TRP(LL,IY)=REAL(TRANSP)
      TIP(LL,IY)=AIMAG(TRANSP)
      OPMH(LL,IY)=CABS(OPTH)
      OPDBH(LL,IY)=20.*ALOG10(OPMH(LL,IY))
      OPAH(LL,IY)=ANGL(OPTH)
      OPRH(LL,IY)=REAL(OPTH)
      OPIH(LL,IY)=AIMAG(OPTH)
      OPMS(LL,IY)=CABS(OPTS)
      OPDBS(LL,IY)=20.*ALOG10(OPMS(LL,IY))
      OPAS(LL,IY)=ANGL(OPTS)
      OPRS(LL,IY)=REAL(OPTS)
      OPIS(LL,IY)=AIMAG(OPTS)
  610 CONTINUE
      LL=1
      DO 852 I1=1,2
      DO 854 I2=1,3
      WH(LL,IY,I1,I2)=H(I1,I2)
  854 CONTINUE
  852 CONTINUE
      GO TO 848
  777 CONTINUE
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      IF(IBODE .EQ. 0)RATIO=OPTK
      IF(IBODE .NE. 0 .AND. DELVI .NE. 0)RATIO=OPTJ
      PER(ICOUNT) = PERIOD
      XREA (ICOUNT) = REAL(RATIO)
      YIMA (ICOUNT) = AIMAG(RATIO)
      AMRAT=CABS(RATIO)
      AMOD(ICOUNT) = AMRAT
      AMRAT=20.*ALOG10(AMRAT)
      ARRAT=ANGL(RATIO)
      ARGU(ICOUNT) = ARRAT
      HWA1=XREA(ICOUNT)**2+YIMA(ICOUNT)**2
      HWA2=SQRT(HWA1)
      AMAG(ICOUNT)=20.*ALOG10(HWA2)
      IF(IBODE .EQ. 1) GO TO 481
C
  481 OLDW=W1
      IF(IREG .EQ. 1.OR.IREG.EQ.2) GO TO 410
      DRAT=CABS(OLDRAT-RATIO)
      IF(IBODE .EQ. 1) GO TO 482
      IF(AMRAT.LE.1.E-15) GO TO 410
  482 DRAREL=DRAT/AMRAT
      IF(DRAREL.GT.0.4)GO TO 500
      IF(DRAREL.LE.0.1) GO TO 510
      GO TO 410
  500 W1=W1/WMUL
      WMUL=SQRT(WMUL)
      IF(WMUL .LT. SIGP1) WMUL = 1.0 + SIG/2.0
      GO TO 410
  510 WMUL=WMUL**2
      GO TO 410
C
C
C
C   $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
  600 CONTINUE
      WRITE(6,68)VOCAL,VFCORE,DOP
   68 FORMAT(///,'VOID COEFFICIENT= ',E12.4,5X,
     @            'CORE AVERAGE VOID FRACTION= ',E12.4,5X,
     @            'DOPPLER COEFFIENT= ',E12.4)
      L=1
      WRITE(6,76)
   76 FORMAT(//,'SYSTEM PRESSURE TO DIMENSIONLESS NEUTRON FLUX')
      WRITE(6,760)
  760 FORMAT(/)
      WRITE(6,762)
  762 FORMAT(6X,'W',9X,'MAG(%)',7X,'DB',7X,'ANGL(DGE)',6X,'REAL'
     @ ,8X,'IMAG')
      WRITE(6,77)(STF(I),CLMP(L,I),CLDBP(L,I),CLAP(L,I),CLRP(L,I),
     @   CLIP(L,I), I=1,IY)
      WRITE(6,78)
   78 FORMAT(//,'EXTERNAL REACTIVITY TO DIMENSIONLESS NEUTRON FLUX')
      WRITE(6,760)
      WRITE(6,761)
  761 FORMAT(6X,'W',9X,'MAG',10X,'DB',7X,'ANGL(DGE)',6X,'REAL',8X,
     @ 'IMAG')
      WRITE(6,77)(STF(I),CLMK(L,I),CLDBK(L,I),CLAK(L,I),CLRK(L,I),
     @   CLIK(L,I), I=1,IY)
      WRITE(6,79)
   79 FORMAT(//,'TOTAL REACTIVITY TO NEGATIVE FEEDBACK REACTIVITY')
      WRITE(6,760)
      WRITE(6,761)
      WRITE(6,77)(STF(I),OPMK(L,I),OPDBK(L,I),OPAK(L,I),OPRK(L,I),
     @   OPIK(L,I), I=1,IY)
      WRITE(6,378)
  378 FORMAT(//,'DIMENSIONLESS CORE FLOW TO DIMENSIONLESS NEUTRON',
     @' FLUX')
      WRITE(6,760)
      WRITE(6,761)
      WRITE(6,77)(STF(I),CLMW(L,I),CLDBW(L,I),CLAW(L,I),CLRW(L,I),
     @   CLIW(L,I), I=1,IY)
      WRITE(6,379)
  379 FORMAT(//,'TOTAL CORE FLOW TO NEGATIVE FEEDBACK CORE FLOW')
      WRITE(6,760)
      WRITE(6,761)
      WRITE(6,77)(STF(I),OPMJ(L,I),OPDBJ(L,I),OPAJ(L,I),OPRJ(L,I),
     @   OPIJ(L,I), I=1,IY)
      WRITE(6,382)
  382 FORMAT(//,'DIMENSIONLESS POWER DENSITY TO DIMENSIONLESS CORE',
     @' FLOW')
      WRITE(6,760)
      WRITE(6,761)
      WRITE(6,77)(STF(I),PJM(L,I),PJDB(L,I),PJA(L,I),PJR(L,I),
     @   PJI(L,I), I=1,IY)
      DO 615 L=1,2
      IF(L .EQ. 1)WRITE(6,611)
      IF(L .EQ. 2)WRITE(6,612)
  611 FORMAT(///,'*** REACTOR NEUTRONICS INCLUDED ***')
  612 FORMAT(///,'*** REACTOR NEUTRONICS EXCLUDED ***')
      WRITE(6,81)
   81 FORMAT(//,'AVERAGE CHANNEL INLET FLOW TO CHANNEL SINGLE ',
     @ 'PHASE PRESSURE DROP')
      WRITE(6,760)
      WRITE(6,761)
      WRITE(6,77)(STF(I),DPM(L,I),DPDB(L,I),DPA(L,I),DPR(L,I),
     @   DPI(L,I), I=1,IY)
      WRITE(6,283)
  283 FORMAT(//,'AVERAGE CHANNEL INLET FLOW TO CHANNEL ',
     @ 'TWO-PHASE PRESSURE DROP')
      WRITE(6,760)
      WRITE(6,761)
      WRITE(6,77)(STF(I),PIM(L,I),PIDB(L,I),PIA(L,I),PIR(L,I),
     @   PII(L,I), I=1,IY)
      WRITE(6,688)
  688 FORMAT(//,'CHANNEL TWO-PHASE PRESSURE DROP / CHANNEL ',
     @ 'SINGLE PHASE PRESSURE DROP')
      WRITE(6,760)
      WRITE(6,761)
      WRITE(6,77)(STF(I),OPMH(L,I),OPDBH(L,I),OPAH(L,I),OPRH(L,I),
     @  OPIH(L,I), I=1,IY)
   77 FORMAT(6E12.4)
      WRITE(6,88)
   88 FORMAT(//,'AVERAGE CHANNEL INLET FLOW TO LOOP SINGLE PHASE ',
     @ 'PRESSURE DROP')
      WRITE(6,760)
      WRITE(6,761)
      WRITE(6,77)(STF(I),TMP(L,I),TDBP(L,I),TAP(L,I),TRP(L,I),
     @   TIP(L,I), I=1,IY)
      WRITE(6,83)
   83 FORMAT(//,'AVERAGE CHANNEL INLET FLOW TO LOOP TWO-PHASE ',
     @ 'PRESSURE DROP')
      WRITE(6,760)
      WRITE(6,761)
      WRITE(6,77)(STF(I),SPM(L,I),SPDB(L,I),SPA(L,I),SPR(L,I),
     @   SPI(L,I), I=1,IY)
      WRITE(6,689)
  689 FORMAT(//,'LOOP TWO-PHASE PRESSURE DROP / LOOP ',
     @ 'SINGLE PHASE PRESSURE DROP')
      WRITE(6,760)
      WRITE(6,761)
      WRITE(6,77)(STF(I),OPMS(L,I),OPDBS(L,I),OPAS(L,I),OPRS(L,I),
     @  OPIS(L,I), I=1,IY)
  615 CONTINUE
      IF(IBODE .NE. 0)GO TO 1090
      ITCT=ICOUNT
      IF(ITCT .LE. 1)GO TO 1090
      ICOUNT = ICOUNT - 1
C
      WRITE(6,15) (I, PER(I), XREA(I), YIMA(I), AMOD(I), ARGU(I),
     1              I= 1, ITCT)
C
C     . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C     *   PLOT  NYQUIST  DIAGRAM
C     . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
      WRITE(6,16)
C
      CALL POLPLT(XREA , YIMA , ICOUNT)
C
C    $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
C     *****    STABILITY MARGIN CALCULATION    *****
C
C                *  STM ; MAGNITUDE MARGIN
C                *  STA ; PHASE MARGIN
C
      STM=9999.
      STA=9999.
      KV = 0
      DO 630 I=2,ITCT
      II = I - 1
      KV = KV+1
      YDIF=YIMA(I)*YIMA(II)
      IF(YDIF .GT. 0.) GO TO 630
      XMAG = XREA(II)+(XREA(I)-XREA(II))/(ABS(YIMA(I))+
     @        ABS(YIMA(II)))*ABS(YIMA(II))
      STM = 20.*ALOG10(-1./XMAG)
      GO TO 640
  630 CONTINUE
C
  640 K2 = 0
      XANG = -180.
      IF(1.-AMOD(1) .GT. 0.) GO TO 660
      DO 650 I=2,ICOUNT
      IF(1.-AMOD(I) .LT. 0.) GO TO 650
      II = I-1
      K2 = K2+1
      IF(AMOD(I) .EQ. AMOD(II))GO TO 1090
      XANG=ARGU(II)+(ARGU(I)-ARGU(II))/(AMOD(I)-AMOD(II))*
     1     (1.-AMOD(II))
      GO TO 660
  650 CONTINUE
  660 CONTINUE
      STA = 180.+XANG
      IF(STM .LE. 0 .OR. XANG .GE. 0.) GO TO 1088
      IF(STM .EQ. 9999. .OR. STA .EQ. 9999.) GO TO 1089
      WRITE(6,17) STM, STA
C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C   ******* MIMO STABILITY MARGINS CALCULATION *********
C                   GM = GAIN MARGIN (DB)
C                   PM = PHASE MARGIN (DEGREE)
```

```
C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      L=1
      NM=4
      M=4
      N=4
      SVMAXF=100000.
      DO 225 K=1,IY
      DO 230 I=1,4
      DO 235 J=1,4
      IM2=I-2
      JM2=J-2
      IF(I .LE. 2)GO TO 240
      IF(J .LE. 2)GO TO 250
      A(I,J)=REAL(WM(L,K,IM2,JM2))
      GO TO 235
  250 A(I,J)=AIMAG(WM(L,K,IM2,J))
      GO TO 235
  240 IF(J .LE. 2)GO TO 245
      A(I,J)=-AIMAG(WM(L,K,I,JM2))
      GO TO 235
  245 A(I,J)=REAL(WM(L,K,I,J))
  235 CONTINUE
  230 CONTINUE
      CALL SVD(NM,M,N,A,SV,.FALSE.,U,.FALSE.,V,IERR,WORK)
      IF(IERR .NE. 0)WRITE(6,222)IERR
  222 FORMAT('TROUBLE IERR = ',I4)
      DO 242 I=1,4
  242 SVMAX(K)=AMAX1(SVMAX(K),SV(I))
      SVMAX(K)=1./SVMAX(K)
      SVMAXF=AMIN1(SVMAXF,SVMAX(K))
  225 CONTINUE
      GM=20.*ALOG10(1.+SVMAXF)
      NSIG=SVMAXF/2.
      IF(NSIG .GE. 1)SVMAXF=SVMAXF-2.*FLOAT(NSIG)
      PM=2.*ARSIN(SVMAXF/2.)*180./3.14159
      WRITE(6,255)GM,PM
  255 FORMAT(///,15X,'MIMO STABILITY MARGINS',/15X,
     @       'GAIN  MARGIN = ',F9.4,' (DB)',/15X,
     @       'PHASE MARGIN = ',F9.4,' (DEGREE)')
      WRITE(6,257)
  257 FORMAT(//,24X,'W',10X,'1/SIGMA')
      WRITE(6,256)(STF(K),SVMAX(K),K=1,IY)
  256 FORMAT(18X,E12.4,2X,E12.4)
      GO TO 1090
C
C    $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
 5000 WRITE (6,10) XCHOUT(I)
      STOP
C
 4000 WRITE(6,70) KIP1,KIP2
      STOP
C
 6000 WRITE(6,12)
      STOP
C
 1088 WRITE(6,20)
 1089 WRITE(6,202)
 1090 CONTINUE
 2000 CONTINUE
```

```
      STOP
      END
C
C***********************************************************************
      SUBROUTINE POINT(S,ALFAVE,ICE,CKCAAL,PCAPLA,DOP)
C***********************************************************************
      COMPLEX SUM,PPSI,ZPK,ZPKP,CMPLX,S,ZPK1,ZPD
      DIMENSION PBETA(6),PLAMDA(6)
      COMMON/PTK0/ZPK,ZPK1,ZPKP,DRDU,VOCAL
      COMMON/PTK2/ZPD
      DATA PBETA/2.5842E-04,1.51386E-03,1.3751E-03,3.00787E-03,
     @ 1.04661E-03, 2.4178E-04/
      DATA PLAMDA/1.27E-02,3.17E-02,1.15E-01,3.11E-01,1.40, 3.87/
C
      IF(ICE .NE. 0)GO TO 38
      CKEFF=1.
      CALPHA=-.02593-.1163*ALFAVE
      CKCAAL=CKEFF*CALPHA
      GO TO 49
   38 CONTINUE
   49 SUM=CMPLX(0.,0.)
      DO 1070 I=1,6
      SUM=SUM+PBETA(I)*S/(S+PLAMDA(I))
 1070 CONTINUE
      PPSI=SUM/PCAPLA
      ZPK1=1./PCAPLA/(PPSI+S)
      ZPK=CKCAAL*ZPK1
      ZPD=DOP*ZPK1
      RETURN
      END
C
C ...................................................................
      SUBROUTINE TPDP(ICAL,JLL,JRR,L)
C ...................................................................
      COMPLEX DWSW1,DWSW2,DWSW3,T1,GAM1,GAM2,GAM3,PI1,PI2,PI3,
     @         PR1,PR2,PR3,PR3P,PR4,GAM4,TLP,DWSW4,TALP4,PI4,
     @         1LP4,PUP1,PUP2,PUP3,PUP4,DWSW5,GPI1,GPI2,GPI3,
     @         GPI4,QL1,QL2,QL3,QL4,QL2S,QL3S,QL4S,VJ1,VJ2,VJ3,
     @         WW1,WW2,WW1S,WW2S,HIN1S,HIN2S,SUMV3,SUMV2,
     @         GPI3S(5),GPI4S(5)
      COMPLEX CXA2,CXA3,RR1,RR2,RR3,DPUP1,DPUP2,DPUP3,DPH1,DPUP4,
     @         TALP1,TSUM2,TAU1,TAU2,TALP3,STC3,STC4,STC5,STC6,
     @         PP,TALP2
      COMMON/CONSS2/ NTOT(5),NBB(5),NBB1(5),NSP,N1PSP(5),
     1              K2PSP(5), NDP(5), NDP1(5), ISUB(5)
      COMMON/CONST2/ P,VCH,VIN(5),AXS(5),DH(5),DHIN(5),
     1        PH(5).TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2     DENSF,VFG1,RHOG,G0(5),G02(5),H0(5),GC,G1,KLOSS(30),
     3        FRICMO(5),VGJH(5,30),COH(5,30),CZERO,VGJ,DPTS,
     4        G02RF(5),HFG1,ZSP(30),NUMBSP(5,30),ALHEAT,CXF(5),
     5        AVEQ,CHOMO1,CHOMO2,XKIN(5),XKEXIT(5)
      COMMON/MULT/NN(5)
      COMMON/YPUP/PUP1(5),PUP2(5,30),PUP3,PUP4
      COMMON/YPR/PR1(5),PR2(5,30),PR3,PR3P,PR4
      COMMON/PPQQ/GAM4(5),PI4(5)
      COMMON/SSS/GPI1(5),GPI2(5,30),GPI3(5),GPI4(5),
     @QL1(5),QL2(5,30),QL3,QL4,QL2S(5,30),QL3S(5),QL4S(5),
     @    VJ1(5),VJ2(5),VJ3(5),WW1(5),WW2,WW1S(5,5),
     @    WW2S(5),HIN1S(5),HIN2S
      COMMON /CXLP/ RR1(5), RR2, RR3, DPUP1(5), DPUP2, DPUP3,
     1                DWSW1(5),DWSW2(5,30),DWSW3,T1,DPH1,DPUP4
      COMMON/STABP/ TLP,DWSW4
      COMMON /DPCON1/GAM1(5),GAM2(5,30),GAM3(5), PI1(5),
     1                PI2(5,30),PI3(5), TALP1(5,30),
     2                TSUM2(5,30),TAU1(5),TAU2(5),TALP3(5,30)
      COMMON/COREP/ STC3(30),STC4(30),STC5(30),STC6(30),PP(30),
     1                TALP2(5,30,30),TALP4(5,30),TLP4,PJ
      COMMON/WSW5/DWSW5
C
C
      DO 1000 I=JLL,JRR
      NP1=NTOT(I)
      GPI1(I)=GAM1(I)+PI1(I)
      DO 57 K=1,NP1
      QL2(I,K)=PUP2(I,K)+PR2(I,K)+DWSW2(I,K)
      IF(L .EQ. 2)QL2(I,K)=CMPLX(0.,0.)
   57 GPI2(I,K)=GAM2(I,K)+PI2(I,K)
      GPI3(I)=GAM3(I)+PI3(I)
      GPI4(I)=GAM4(I)+PI4(I)
      IF(L .EQ. 2)GO TO 10
      QL1(I)=PUP1(I)+PR1(I)+DWSW1(I)
      QL3=PUP3+PR3+DWSW3
      QL4=PUP4+PR4+DWSW4
      GO TO 15
   10 QL1(I)=CMPLX(0.,0.)
      QL3=CMPLX(0.,0.)
      QL4=CMPLX(0.,0.)
   15 CONTINUE
      QL3S(I)=(GPI3(I)+QL3)*TLP+DWSW5
      QL4S(I)=GPI4(I)+QL4+(GPI3(I)+QL3)*TLP4
      GPI3S(I)=GPI3(I)*TLP
      GPI4S(I)=GPI4(I)+GPI3(I)*TLP4
 1000 CONTINUE
      DO 1100 I=JLL,JRR
      VJ1(I)=CMPLX(0.,0.)
      VJ2(I)=CMPLX(0.,0.)
      VJ3(I)=CMPLX(0.,0.)
      IF(JRR .EQ. 1)GO TO 62
      DO 59 J=JLL,JRR
      IF(J .EQ. I)VJ1(I)=VJ1(I)+(NN(I)-1)*QL1(J)*GPI1(I)/GPI1(J)
      IF(J .NE. I)VJ1(I)=VJ1(I)+NN(J)*QL1(J)*GPI1(I)/GPI1(J)
      VJ2(I)=VJ2(I)+NN(J)*QL1(J)/GPI1(J)*(GPI4S(I)-GPI4S(J))
      VJ3(I)=VJ3(I)+NN(J)*QL1(J)/GPI1(J)*(GPI3S(I)-GPI3S(J))
   59 CONTINUE
      VJ1(I)=VJ1(I)+GPI1(I)+QL1(I)
      GO TO 636
   62 VJ1(I)=GPI1(I)+QL1(I)*NN(I)
  636 VJ1(I)=-1./VJ1(I)
      VJ2(I)=VJ2(I)+QL4S(I)
      VJ2(I)=VJ1(I)*VJ2(I)
      VJ3(I)=VJ3(I)+QL3S(I)
      VJ3(I)=VJ1(I)*VJ3(I)
 1100 CONTINUE
      SUMV3=CMPLX(0.,0.)
      SUMV2=CMPLX(0.,0.)
      DO 64 I=JLL,JRR
      SUMV2=SUMV2+DENSI*AXS(I)*VJ2(I)*NN(I)
   64 SUMV3=SUMV3+DENSI*AXS(I)*VJ3(I)*NN(I)
      DO 66 I=JLL,JRR
   66 WW1(I)=DENSI*AXS(I)*VJ1(I)/(1.-SUMV3)
```

```
      WW2=SUMV2/(1.-SUMV3)
      DO 68 I=JLL,JRR
      DO 172 M=JLL,JRR
  172 WW1S(I,M)=VJ3(I)*WW1(M)
   68 WW2S(I)=VJ2(I)+VJ3(I)*WW2
      DO 74 M=JLL,JRR
   74 HIN1S(M)=TLP*WW1(M)
      HIN2S=TLP*WW2+TLP4
      RETURN
      END
C
C
C
C
C
C    $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C    $                                                           $
C    $     PLOTING   SUBROUTINE    FOR   NYQUIST   DIAGRAM       $
C    $                                                           $
C    $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
C*********************************************************************
      SUBROUTINE POLPLT(XREAL, YIMAG, NUM)
C*********************************************************************
C
C     SUBROUTINE POLPLT PLOTS POLAR DIAGRAMS IN THE COMPLEX PLANE
C     XREAL - ARRAY OF ABSCISSAS
C     YIMAG - ARRAY OF ORDINATES
C     NUM - NUMBER OF POINTS TO BE PLOTTED  (MUST BE .GE. 2)
C
      INTEGER CHAR(10)
      INTEGER PWIDTH
      DIMENSION IP(100,60), XREAL(1), YIMAG(1)
      COMMON /PLOT/ IP, XORG, YORG, XSLOT, YSLOT, PWIDTH, LENGTH
      DATA IBLNK /1H /, CHAR /      1H1, 1H2, 1H3, 1H4, 1H5, 1H6, 1H7,
     1      1H8, 1H9, 1H0/
      PWIDTH = 100
      LENGTH = 60
C....................................................................
C     DETERMINATION  THE WIDTH OF THE AXES ON THE NYQUIST PLOT
C....................................................................
      XMAX = 0.0
      YMAX = 0.0
      XMIN = 0.0
      YMIN = 0.0
C
      DO 10 IM = 1,NUM
      IF(XMAX - XREAL(IM)) 4,10,10
    4 XMAX = XREAL(IM)
   10 CONTINUE
C
      DO 20 IM = 1,NUM
      IF(YMAX - YIMAG(IM)) 14,20,20
   14 YMAX = YIMAG(IM)
   20 CONTINUE
C
      DO 30 IM = 1,NUM
      IF(XMIN - XREAL(IM)) 30,30,24
   24 XMIN = XREAL(IM)
   30 CONTINUE
```

```
C
      DO 40 IM = 1,NUM
      IF(YMIN - YIMAG(IM)) 40,40,34
   34 YMIN = YIMAG(IM)
   40 CONTINUE
C
      ABSXY = AMAX1(ABS(XMAX), ABS(YMAX), ABS(XMIN), ABS(YMIN))
      IF(ABSXY - 0.1) 51, 52, 52
   51 IEXP = INT(ALOG10(ABSXY))
      AMULT = 10.0**IEXP
      GO TO 53
   52 AMULT = 1.0
   53 CONTINUE
      IF(XMAX .LT. AMULT) XMAX = AMULT
      IF(YMAX .LT. AMULT) YMAX = AMULT
      IF(XMIN .GT. (-AMULT)) XMIN = -AMULT
      IF(YMIN .GT. (-AMULT)) YMIN = -AMULT
      XSLOT = FLOAT(PWIDTH - 1)/(XMAX - XMIN)
      YSLOT = FLOAT(LENGTH - 1)/(YMAX - YMIN)
      XORG = (XMAX - FLOAT(PWIDTH)*XMIN)/(XMAX - XMIN) + 0.5
      YORG = (YMAX - FLOAT(LENGTH)*YMIN)/(YMAX - YMIN) + 0.5
C..........................................................................
C     ERASE SURFACE OF PAPER
C..........................................................................
      DO 102 K = 1, PWIDTH
      DO 102 L = 1, LENGTH
  102 IP(K,L) = IBLNK
C..........................................................................
C     DRAW AXES
C..........................................................................
      CALL YLINE(-1.0*AMULT)
      CALL YLINE( 0.0)
      CALL YLINE(+1.0*AMULT)
      CALL XLINE(-1.0*AMULT)
      CALL XLINE( 0.0)
      CALL XLINE(+1.0*AMULT)
C..........................................................................
C     DRAW DIAGRAM
C..........................................................................
      DO 105 KJ = 2,NUM
  105 CALL LINE(XREAL(KJ-1), YIMAG(KJ-1), XREAL(KJ), YIMAG(KJ))
C..........................................................................
C     LABEL POINTS TO BE PRINTED
C..........................................................................
      DO 106 KJ = 1, NUM
      IND = MOD(9 + KJ, 10) + 1
  106 CALL PTTY(XREAL(KJ), YIMAG(KJ), CHAR(IND))
C..........................................................................
C     PLOT DIAGRAM ON PLOTTER
C..........................................................................
      WRITE(6,112) (IP(KI,1), KI = 1,PWIDTH), AMULT
  112 FORMAT(1H , 3X, 100A1, 6HSCALE=, 1PE7.1)
      DO 110 KJ = 2, LENGTH
  110 WRITE(6,111) (IP(KI,KJ), KI = 1,PWIDTH)
  111 FORMAT(1HZ, 3X, 100A1)
      RETURN
      END
C
C
C
```

```
C
C*****************************************************************
      SUBROUTINE LINE(X11, Y11, X22, Y22)
C*****************************************************************
C
C     SUBROUTINE LINE DRAWS A LINE BETWEEN POINTS 1 AND 2
C
      INTEGER PWIDTH
      DIMENSION IP(100,60)
      COMMON /PLOT/ IP, XORG, YORG, XSLOT, YSLOT, PWIDTH, LENGTH
      DATA IDOT /1H*/
C
      ICX(Z) = IFIX(XORG + Z*XSLOT)
      ICY(Z) = IFIX(YORG + Z*YSLOT)
C
      X1 = X11
      X2 = X22
      Y1 = Y11
      Y2 = Y22
C..................................................................
C     TO ENSURE LINE IS DRAWN FROM TOP TO BOTTOM
C..................................................................
      IF(Y1 .GE. Y2) GO TO 6
      X3 = X1
      Y3 = Y1
      X1 = X2
      Y1 = Y2
      X2 = X3
      Y2 = Y3
C
    6 J1 = LENGTH + 1 - ICY(Y1)
      J2 = LENGTH + 1 - ICY(Y2)
      RXSLOT = 1.0/XSLOT
      IF(ABS(X1-X2) .LE. RXSLOT) GO TO 10
      IF(J1 .EQ. J2) GO TO 20
      GRADE = (X2 - X1)/FLOAT(J2 - J1)
      DO 1 J = J1, J2
      I = ICX(X1 + FLOAT(J - J1)*GRADE)
    1 IP(I,J) = IDOT
      RETURN
C
   10 I = ICX(0.5*(X1 + X2))
      DO 11 J = J1,J2
   11 IP(I,J) = IDOT
      RETURN
C
   20 I11 = ICX(X1)
      I22 = ICX(X2)
      I1 = MIN0(I11,I22)
      I2 = I11 + I22 - I1
      DO 21 I = I1, I2
  21  IP(I,J1) = IDOT
      RETURN
      END
C
C
C
C
C******************************************************************
      SUBROUTINE XLINE(Y)
```

```
C**********************************************************************
C
C     PLOTS HORIZONTAL AXES
C
      INTEGER PWIDTH
      DIMENSION IP(100,60)
      COMMON /PLOT/ IP, XORG, YORG, XSLOT, YSLOT, PWIDTH, LENGTH
      DATA MINUS /1H-/
C
      J = LENGTH + 1 - IFIX(YORG + Y*YSLOT)
      DO 1 I = 1,PWIDTH
  1   IP(I,J) = MINUS
      RETURN
      END
C
C
C**********************************************************************
      SUBROUTINE YLINE(X)
C**********************************************************************
C
C     PLOTS VERTICAL LINES
C
      INTEGER PWIDTH
      DIMENSION IP(100,60)
      COMMON /PLOT/ IP, XORG, YORG, XSLOT, YSLOT, PWIDTH, LENGTH
      DATA IBAR /1HI/
C
      I = IFIX(XORG + X*XSLOT)
      DO 1 J = 1, LENGTH
    1 IP(I,J) = IBAR
      RETURN
      END
C
C
C**********************************************************************
      SUBROUTINE PTTY(X, Y, IC)
C**********************************************************************
C
C     PLOTS A POINT ON THE LINE PRINTER
C
      INTEGER PWIDTH
      DIMENSION IP(100,60)
      COMMON /PLOT/ IP, XORG, YORG, XSLOT, YSLOT, PWIDTH, LENGTH
C
      ICX(Z) = IFIX(XORG + Z*XSLOT)
      ICY(Z) = IFIX(YORG + Z*YSLOT)
      I  = ICX(X)
C
      J = LENGTH + 1 - ICY(Y)
      IP(I,J) = IC
      RETURN
      END
C
C
C
C
C************************************
      SUBROUTINE CONSS(I,ICH,ICAL,IWIT)
C************************************
C       ....... CALCULATE THE STEADY-STATE CONSTANTS & SYSTEM PARAMETERS
```

```
      REAL KF, KLOSS, MUTL ,MARNEL
      COMPLEX DGAMP
      NAMELIST/CALPRO/ ENTHT,ENTHP,DENSF,DENSI,VFG1,RHOG
      NAMELIST/PROPTY/ TSATP,TAVE,HFG1,VISC,CPF,KF,SIGM
      COMMON/CONST1/ C1(5),C2(5),C3(5),C4,C5(5),C8(5,30),
     1       C9(5,30),C18(5), C21(5), C22(5),C25(5),
     2       C26(5), T6, V7(5), DD1, CKI, CMP
      COMMON/CONST2/ P,VCH,VIN(5),AXS(5),DH(5),DHIN(5),
     1       PH(5),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2       DENSF,VFG1,RHOG,G0(5),G02(5),H0(5),GC,G1,KLOSS(30),
     3       FRICHO(5),VGJH(5,30),COH(5,30),CZERO,VGJ,DPTS,
     4       G02RF(5),HFG1,ZSP(30),NUMBSP(5,30),ALHEAT,CXF(5),
     5       AVEQ,CHOMO1,CHOMO2,XKIN(5),XKEXIT(5)
      COMMON /CUPPER/ RKIN,RKEXIT,AP,RP0,RP1,RP2,CL10(5),
     1   CL11(5),CLT,AXSCH,RAR,AD,DL,DHDL,FDL, F1(5),F2(5),
     2                RJ1(5),RJ2(5),RJ3(5),F3(5)
      COMMON /CDELH1/ HFW, ADC, PHV, DKV, CPV, DENV, TEMV, TEMINV,
     1                THV, HGS, PLM, AHLP, THLP, HOLP, WO, DLENG
C
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMMON/DELTAP/DGAMP,DRHOG,DHF,DHG,DCZERO,DVGJ,DCOR,DVGJR
      COMMON/SWITCH/IDCZC,IDVGJC,IDCZR,IDVGJR
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
   10 FORMAT(////10X,'***** SYSTEM PROPERTIES *****')
C
      IF(IWIT .GE. 1) GO TO 20
      TSAT=TSATP
      TAVE=(TIN+TSAT)/2.
      ENTHT=HL(P,TIN)
      ENTHP=HF(P)
      HFG1=HFG(P)
      VISC=MUTL(TAVE)/3600.0
      VISDL=MUTL(TSAT)/3600.0
      SIGM = SGMA(P,TSATP)
C
      CPF= (HL(P,TSAT)-ENTHT)/(TSAT-TIN)
      KF=COND(TAVE)/3600.
      DENSI = DENS(P,TIN,DUMB)
      DENSF=DENS(P,TAVE,DUMB)
      VFG1 = VFG(P)
      VGAS =  VFG1 + VF(P)
      RHOG = 1.0/VGAS
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C DETERMONE STATE PARAMETERS AS A FUNCTION OF PRESSURE
      DRHOG=-(RHOG**2)*DVG1(P)
      DHF=DHF1(P)
      DHG=DHG1(P)
      DCZERO=DCZER1(RHOG,DENSF,DRHOG,IDCZC)
      DVGJ=DVGJ1(RHOG,DENSF,DRHOG,TAVE,P,IDVGJC)
      DCOR=DCZER1(RHOG,DENSF,DRHOG,IDCZR)
      DVGJR=DVGJ1(RHOG,DENSF,DRHOG,TAVE,P,IDVGJR)
      IF(IWIT .LT. 2)GO TO 15
      WRITE(6,481) DRHOG,DHF,DHG
      WRITE(6,482) DCZERO,DVGJ,DCOR,DVGJR
  481 FORMAT(' ','DRHOG=',E10.3,'DHF=',E10.3,'DHG=',E10.3)
  482 FORMAT(' ','DCZERO=',E10.3,'DVGJ=',E10.3,'DCOR=',E10.3,'DVGJR=
     @ ',E10.3)
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
   15 CONTINUE
      DH(I) = DHIN(I)/12.0
```

```
C
   20 VIN(I)=VCH
      GO(I)=DENSF*VIN(I)
      GO2(I) = GO(I)**2
      GO2RF(I) = GO2(I)/(2.0*DENSF*GC)
      HO(I)=KF/DH(I) * .023 * (DENSF*VIN(I)*DH(I)/VISC)**(0.8)
     1       * (CPF*VISC/KF)**(0.4)
C
C     * CALCULATION OF THE SINGLE-PHASE DARCY-WEISBACH FRICTION FACTOR
C               BY FITTING THE MOODY CURVES
C         @  RPD ; SURFACE ROUGHNESS / DH(I)  IN COMMERCIAL STEEL PIPE
C         @  RE  ; RENOLD'S NUMBER
      RPD = -1.41E-05*DHIN(I) + 3.36E-04
      RE  =  GO(I)*DH(I)/VISC
      FRICMO(I) = 0.0055*( 1.0 + (20000.*RPD + 1.0E+06/RE)**(1./3.) )
C
      IF(ICAL .GE. 2 ) GO TO 200
       GO TO 201
  200 RDL = -1.41E-05*(DHDL/12.0) + 3.36E-04
      REDL = (WO/AD)*DHDL/VISDL
      FDL = 0.0055*(1.0+(20000.*RDL + 1.0E+06/REDL)**(1./3.) )
      FDL=.184/(2.*DHDL*REDL**.2)
C
  201 IF(IWIT .GE. 1) GO TO 30
      T6 = G1/GC*DENSF
      C4 = DENSF - RHOG
      C5(I) = PH(I)*VFG1/(AXS(I)*HFG1)
      C25(I) = C4*PH(I)/AXS(I)/DENSF
C
   30 V7(I) = FRICMO(I)*GO(I)*VIN(I)/(2.*GC*DH(I))
      C1(I) = PH(I)/(DENSF*VIN(I)*CPF*AXS(I))
      C2(I) = V7(I) + T6
      C3(I) = FRICMO(I)*GO(I)/(GC*DH(I))
      C18(I) = CXF(I)/(GO(I)*AXS(I))
      DD1 = MARNEL(P,GO(I)) * (1.2*(DENSF/RHOG) - 1.)
      XFRIC=MARNEL(P,GO(I))
C
      IF(IWIT .GE. 1) GO TO 100
      IF(ICH .EQ. 0) GO TO 100
      WRITE(6,10)
      WRITE(6,CALPRO)
      WRITE(6,PROPTY)
  100 RETURN
      END
C
C
C
C
C***********************************************************
      SUBROUTINE STEADY(NODES,INODE,ICH,ICAL,IWIT,CHALF,RPWR)
C***********************************************************
C     * CALCULATE STEADY-STATE VALUES
C     * LAMDDA ; BOILING BOUNDARY
C     * JOIN(I) ; NODE INLET FLOW VELOCITY
C     * DOIN(I); NODE INLET DENSITY
C     * XEXIT ; STEADY-STATE CHANNEL EXIT QUALITY
C     * ALFNOD(INODE,I) ; NODE AVERAGE VOID FRACTION
C
      REAL K1,JOIN,KF,KLOSS
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
```

```
      COMPLEX CLTX,RR4
      COMPLEX CSBX3, DGAMP,VPL
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      DIMENSION DPH2PG(30), H(30),CZ(30),VGZ(30),THALL(30),DPSP(30),
     1      DPH2PF(30),DPH2PA(30),DPH2P(30),TLIQ(30),CKSP(30),
     2      XEXIT(30), JOIN(30),RPWR(5)
      DOUBLE PRECISION XAVG,OMG,DELOMG,CTEM0,CTEM1,CTEM2,CTEM3,OMIN,
     1       OMAX, SBHOUT(30),SBHIN(30),V1(30),ALPOUT(30),AVGH(30),
     2       VOOUT(30),CKOUT(30),OLDOMG(100),DIFF(100),C15(30),
     3       C101(30),C103(30),C104(30),C105(30),C16(30),
     4       C107(30),C108(30),C109(30),C110(30)
C
      NAMELIST/PECT/PE,ENTHP,QFLUX,GFLUX,CRIT,DHI,CPF,KF
      COMMON/OPTION/ IOSUB, IOHW, IO2Q, IPILO, ISLIP, IRW
      COMMON/CONST1/ C1(5),C2(5),C3(5),C4,C5(5),C8(5,30),
     1       C9(5,30),C18(5), C21(5), C22(5),C25(5),
     2       C26(5), T6, V7(5), DO1, CKI, CMP
      COMMON /CONSUB/ CSB2(5,30),CSB3(5,30),CSB4(5,30),
     1       CSB5(5,30),CSB6(5,30),CSB7(5,30),CSB8(5,30),
     2       CSB9(5,30),CSB10(5,30),CSBQ(5,30),CSBD(5,30),
     3       CSBE(5,30),CSBF(5,30), CSBG(5,30),CSBX1(5),
     4       CSBX2(5)
      COMMON/CONST2/ P,VCH,VIN(5),AXS(5),DH(5),DHIN(5),
     1       PH(5),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2       DENSF,VFG1,RHOG,G0(5),G02(5),HO(5),GC,G1,KLOSS(30),
     3       FRICMO(5),VGJH(5,30),COH(5,30),CZERO,VGJ,DPTS,
     4       G02RF(5),HFG1,ZSP(30),NUMBSP(5,30),ALHEAT,CXF(5),
     5       AVEQ,CHOMO1,CHOMO2,XKIN(5),XKEXIT(5)
      COMMON /CONWD1/ CPH,TKH,DENSH,CPC,TKC,DENSC,CRS,CRI,CRO,
     1                GAPC,V22(5,30), THICKH
C
      COMMON /RISER/ COR,VGJR,CKRO,RL,AR,DRIN,DR,PI,CL1,CL2,CL3,CL4,
     1    CL5, CL6, CR5, CR6, UPJ1(5), UPJ2(5), RO11, RO12,
     2               RO21, RO22, XROUT, UPJIN
      COMMON /CLOOP/ SLOOP, SFLOOP, RLOOP,AA,
     @               VL1(5), VL2(5), VL3(5), DPLPT,RATW
      COMMON/CUPPER/RKIN,RKEXIT,AP,RPO,RP1,RP2,CL10(5),CL11(5),
     1              CLT,AXSCH,RAR,AD,DL,DHDL,FDL, F1(5),F2(5),
     2              RJ1(5),RJ2(5),RJ3(5),F3(5)
      COMMON /CDELH1/ HFW, ADC, PHV, DKV, CPV, DENV, TEMV, TEMINV,
     1                THV, HOD, PLM, AHLP, THLP, HOLP, WO, DLENG
      COMMON /CDELH2/ CH1, CH2, CH3, CH4, CH5, CH7, CH8, CH9, CH10
C
      COMMON/CONSS1/ QDIS(5,30),Q0(5,30),DZ(5,30),Z(5,30),
     1       K1(5,30), CKIN(5,30), ZETA(5,30), DOIN(5,30),
     2       DOOUT(5,30),ALPIN(5,30),BEE(5,30),CPI1(5,30),
     3       COR2PH(5,30), ZETSP(5,30), WIN
      COMMON /DIM1/ DELX, DELZ, CHLAMB(5), ALFNOD(5,30),
     1              BBLAMB(5)
      COMMON/CONSS2/ NTOT(5),NBB(5),NBB1(5),NSP,N1PSP(5),
     1               K2PSP(5), NDP(5), NDP1(5), ISUB(5)
      COMMON/PCHOUT/XCHOUT(5), ACHOUT(5), CCHOUT(5)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMMON/RISERP/CLTX,RR4,CRP5,CRP8,RO13,RO23,CL12,UPJ3,ALPRO
     1              ,COR,RHOR,VRO,CRCON,UPALP
      COMMON/SUBP/YSTAR(5,30),ENHTP
      COMMON/SUBPP/PVGH(5,30).
      COMMON/SWITCH/IDCZC,IDVGJC,IDCZR,IDVGJR
      COMMON/KEY/THO,IKEY
      COMMON/PXX/PXEXT(5,30)
      COMMON/PSP/CSBX3(5,30),ALOUT(5,30)
      COMMON/YYY/ZLUP,FLUP,GOU,DHUP,ROUP,FUP,ZLR,FLR,ROF,FRR
     @           ,ADLP,DHLP,ZLLP,FLLP,XKLP,GOLP,FLP
     @           ,AD1,DH1,ZL1,FL1,XK1,GO1,FD1
     @           ,AD2,DH2,ZL2,FL2,XK2,GOD2,FD2
     @           ,AD3,DH3,ZL3,FL3,XK3,GO3,FD3
     @           ,SPUMP,CPUMP
      COMMON/DELTAP/DGAMP,DRHOG,DHF,DHG,DCZERO,DVGJ,DCOR,DVGJR
      COMMON/PIV/IV
      COMMON/VV4/PL1,PL2,PL4
      COMMON/VV5/VPL
      COMMON/CFSUB/CF(5,30),CG(5,30)
      COMMON/PGAM/IGAM,IDRF
      COMMON/PCO/ICO
      COMMON/HLP/PHL(5,30),EPSUB(5,30)
      COMMON/THETA/THETAB
      COMMON/SBHP/B4K(5,30),B5K(5,30),BTEMO(5,30),AVGX(5,30)
C   QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
C     * VIN IS THE AVERAGE VELOCITY IN THE SINGLE-PHASE REGION.
C             ALL CALCULATIONS ARE BASED ON THIS VELOCITY.
C
C     ...................................................................
C     * FORMAT STATEMENTS
C     ...................................................................
    3 FORMAT(/10X, '***   NO BULK BOILING ALONG THE CHANNEL ; HEXIT =',
     1             E12.4, '  (BTU/LBM)   ***')
    5 FORMAT(/3X,'STEADY STATE VOID FRACTION WITH CONSTANT CO &VGJ')
    7 FORMAT(/3X,'STEADY STATE VOID FRACTION WITH VARIABLE CO &VGJ')
    9 FORMAT(2E15.5)
   11 FORMAT(//,'CHANNEL GEOMETRY & BOILING BOUNDARY',//,'TYPE',2X,
     1       'FLOW AREA', 2X,'HEAT PERI.', 2X,'HYDR.DIAM.', 2X,
     2       'BOIL.BNDY.', 2X, 'FUEL AREA ',2X,'    VIN     ',2X,
     3       '    KIN    ',2X, '   KEXIT   ',2X,'POWER DIS.',
     4       /,I3,2X,8(E10.4,2X),E10.4)
   41 FORMAT(///'HEATED WALL DYNAMICS PARAMETER')
   43 FORMAT(/5X, '*****  NO HEATER WALL DYNAMICS  ****' )
   45 FORMAT(/5X,'*** LAMPED PARAMETER MODEL ***',
     1    //10X,'SPECIFIC HEAT OF HEATER    =', E12.6, '(BTU/LB-F)'
     2     /10X,'DENSITY OF HEATER          =', E12.6, '(LB/FT3)')
   47 FORMAT(/5X,'***   TWO-PARALLEL PLATE HEATER   ***',//10X,
     1       'SPECIFIC HEAT OF HEATER    =',E12.6,'(BTU/LB-F)',/10X,
     2       'DENSITY OF HEATER          =',F9.4, '(LB/FT3)'  ,/10X,
     3       'THICKNESS OF HEATER        =',F9.4, '(FT)'       )
   49 FORMAT(/5X,'***   CYLINDRICAL INTERNALLY HEATING TUBE   ***',
     1 /10X, 'SPECIFIC HEAT OF HEATER    =',E12.6,'(BTU/LB-F)',/10X,
     2       'DENSITY OF HEATER          =',F9.4, '(LB/FT3)'  ,/10X,
     3       'INNER RADIUS OF TUBE       =',F9.4, '(FT)'      ,/10X,
     4       'OUTER RADIUS OF TUBE       =',F9.4, '(FT)'       )
   51 FORMAT(/5X,'***   HOMOGENIZED FUEL ASSEMBLY   ***',//7X,
     *       '* FUEL REGION'/10X,
     1       'SPECIFIC HEAT OF FUEL    =',E12.6,'(BTU/LB-F)',/10X,
     2       'THERMAL CONDUCTIVITY     =',E12.6,'(BTU/S-FT-F)',/10X,
     3       'DENSITY OF FUEL          =',F9.4, '(LB/FT3)'  ,/10X,
     4       'FUEL RADIUS              =',F9.4, '(FT)'      ,//7X,
     5       '* CLAD REGION'/10X,
     6       'SPECIFIC HEAT OF CLAD    =',E12.6,'(BTU/LB-F)',/10X,
     7       'THERMAL CONDUCTIVITY     =',E12.6,'(BTU/S-FT-F)',/10X,
     8       'DENSITY OF CLAD          =',F9.4, '(LB/FT3)'  ,/10X,
     9       'INNER RADIUS OF CLAD     =',F9.4, '(FT)'      ,/10X,
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     *      'OUTER RADIUS OF CLAD      =',F9.4, '(FT)'       ,//7X,
     1      'GAP CONDUCTANCE           =',E12.6,  '(BTU/FT2-F)',/)
  57 FORMAT(//10X,'NODE',11X,'Z',7X,'HEAT FLUX',7X,'POWER DENSITY',
     @      9X,'TL',10X,'TWALL')
  59 FORMAT(/10X, '***** TWO-PHASE REGION *****')
  61 FORMAT(/10X,I3,5X,F10.4,3X,F10.4,8X,E12.6,7X,F6.2,7X,F6.2)
  67 FORMAT(1X,///,'NODE PROPERTIES',//5X,'NODE',5X,'DELZ',
     1   8X,'K1',13X,'CO(Z)', 5X,'VGJ(Z)', 6X,'AVG.VOID',4X,'XEXIT(Z)',
     2   6X,'AVG.ENTH.',8X,'JOIN')
  69 FORMAT(/5X,I4,2X,F9.4,3X,E10.4,3(3X,F9.4),2(3X,E12.5),3X,E12.4)
  71 FORMAT(///'LOCAL PRESSURE DROP BY SPACER',
     1       //11X,'Z', 13X,'LOCAL COEFF.', 7X,'LOCAL DP')
  73 FORMAT(/6X,F9.4,   10X,E12.6,   5X,E12.6)
  75 FORMAT(1X,///,'STEADY-STATE PRESSURE DROP',//3X,
     1      SINGLE-PHASE REGION',/6X,'LOCAL LOSS =',F10.4,'(PSI)',
     2     /6X,'GRAVITY =',F10.4,'(PSI)',16X,'FRICTION =',F10.4,
     3      '(PSI)',/6X,'TOTAL DP =',F10.4,'(PSI)')
  77 FORMAT(///3X,'    TWO-PHASE REGION',  //27X,'GRAVITY', 9X,
     1      'FRICTION(COR2PH)', 9X,'ACCELERATION', 5X,'TOTAL',
     2     /6X, 'NODE', 5X, 'Z', 12X,'(PSI)', 10X,'(PSI)',
     3      6X,7X, 10X,'(PSI)',10X,'(PSI)'  )
  79 FORMAT(75X,I4, F10.4, 2(5X,F10.4), ' (',F9.4,')', 2(5X,F10.4))
  81 FORMAT(/6X,'TOTAL',13X,F10.4,5X,F10.4,17X,F10.4,5X,F10.4,
     @       //6X,'LOCAL LOSS =',F10.4,'(PSI)',
     @      /3X,'TOTAL CHANNEL PRESSURE DROP =',F10.4,'(PSI)')
C
  85 FORMAT(/10X,'***     THE ITERATION FOR S.B. DIVERGES ***')
  87 FORMAT(/10X, '***      ERROR ; EXIT QUALITY (', F9.4,
     1              '  )  IS GREATER THAN 1.   ***' )
C      ..........       COMMENTS      ...................................
C      ISUB = 0    ;   THERE IS SINGLE-PHASE REGION
C           = 1    ;   NO SINGLE-PHASE REGION
C      IWIT = 0    ;   SINGLE CH. CALC. OR INITIAL CALC. FOR MULTI-CH.
C                         CALCULATION
C           = 1    ;   MULTI-CHANNEL CALCULATION
C           = 2    ;   FINAL CALCULATION FOR MULTI-CHANNEL CALCULATION
C      NDP1  ;  FIRST NODE INDEX IN THE SUBCOOLED BOILING REGION
C      NBB1  ;  FIRST NODE INDEX IN THE BULK BOILING REGION
C      ..................................................................
      DRF=DRFDP(P)
      IF(IDRF .EQ. 0)DRF=0.
      DDR=DRHOG-DRF
      DRGFP=DRHOG-RHOG/DENSF*DRF
      IF(IWIT .GE. 1) GO TO 100
      H(1) = ENTHI
      CRIT = ENTHP
       AA1 = 23.
       AA2 = 0.
 100  GOHR = GO(INODE)*3600.0
      DHI=DH(INODE)
      PE = GO(INODE)*DH(INODE)*CPF/KF
C
C     * DETERMINE THE VOID DEPARTURE POINT WITH SAHA & ZUBER'S MODEL
C
         ISUB(INODE) = 0
         ITER = 0
         IBB = 0
         NP1 = NODES
         INNSP=0
      DO 120 J=1,NP1
```

```
        JNOD = J
        JA = J + 1
        JN = J - 1
        QFLUX = QDIS(INODE,J)*CXF(INODE)/PH(INODE)
        BEE(INODE,J) = QDIS(INODE,J) /AVEQ
        QO(INODE,J) = QFLUX
       H(JA) = H(J) + QFLUX*PH(INODE)*DZ(INODE,J)/AXS(INODE)/
     1                GO(INODE)
       IF(IOSUB .EQ. 0) GO TO 1000
       IF(PE .LE. 7.0E+04) GO TO 122
        GFLUX=GO(INODE)
        SBX1=-154./GO(INODE)
        SBX2=154.*QFLUX/GO(INODE)**2
        CRIT = ENTHP - 1.53846E+02*QFLUX/GO(INODE)
       IF(H(JA) .GE. CRIT) GO TO 123
       GO TO 120
  122   CRIT = ENTHP - 2.1978E-03*QFLUX*DH(INODE)*CPF/KF
       GFLUX=GO(INODE)
       SBX1=-.0022*DH(INODE)*CPF/KF
       SBX2=0.
       IF(H(JA) .GE. CRIT) GO TO 123
       GO TO 120
 1000  IF(H(JA) .GE. ENTHP) GO TO 124
  120 CONTINUE
C
  123  IF(H(1) .GE. CRIT) GO TO 150
C
  124   NDP(INODE) = JNOD
        INN = NDP(INODE)
        NDP1(INODE) = JNOD + 1
        NDM2 = JNOD - 1
        IF(NDM2 .EQ. 0)NDM2=1
       IF(IOSUB .EQ. 0) GO TO 1001
        DZVD = (CRIT-H(JNOD))*AXS(INODE)*GO(INODE)/QFLUX/PH(INODE)
       IF(DZVD .LT. 0.) GO TO 131
       GO TO 140
 1001   DZVD = (ENTHP-H(INN))*GO(INODE)*AXS(INODE)/(QDIS(INODE,INN)
     1          *CXF(INODE))
       GO TO 140
  131   QFLUX=(QO(INODE,JNOD)+QO(INODE,NDM2))/2.
        CRIT = ENTHP - 1.53846E+02*QFLUX/GO(INODE)
        IF(PE .LE. 7.0E+04) CRIT = ENTHP - 2.1978E-03*QFLUX*DH(INODE)
     1         *CPF/KF
        DZVD = (CRIT-H(NDM2))*AXS(INODE)*GO(INODE)/QFLUX/PH(INODE)
       IF(DZVD .GE. DZ(INODE,NDM2)) GO TO 132
        NDP(INODE) = NDM2
        NDM2 = NDM2 - 1
        INN = NDP(INODE)
        NDP1(INODE) = INN + 1
       GO TO 140
  132   DZVD = DZVD - DZ(INODE,NDM2)
  140  IF(NDM2 .EQ. 0) GO TO 141
        ZSUM = 0.
      DO 142 I=1,NDM2
        ZSUM = ZSUM + DZ(INODE,I)
        Z(INODE,I) = ZSUM
  142 CONTINUE
         CHLAMB(INODE) = ZSUM + DZVD
      GO TO 143
  141    CHLAMB(INODE) = DZVD
```

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C
C      * NODE REDISTRIBUTION IN THE SUBCOOLED BOILING REGION
C
  143 IF(CHLAMB(INODE) .LE. 0.)CHLAMB(INODE)=0.005
      CALL ASSIGN(NDP(INODE), NP1, CHLAMB(INODE), 0, INODE, 0)
      GO TO 160
C
  150   ISUB(INODE) = 1
        NDP1(INODE) = 1
      GO TO 170
  160   NP1 = NP1 + 1
  170   INN1 = NDP1(INODE)
C      . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C      * CALCULATE THE THERMAL PARAMETERS IN THE SUBCOOLED BOILING
C                     REGION
C      . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C
C       C101(J) = ALPIN(INODE,J)
C       C103(J) = JOIN(J)
C       C104(J)= CKIN(INODE,J)
C       C105(J) = ZETA(INODE,J)
C       C106(J) = DOOUT(INODE,J)
C       C107(J) = XEXIT(J)
C       C108(J) = ALFNOD(INODE,J)
C       C109(J) = CSB2(INODE,J)
C       C110(J) = CSB3(INODE,J)
C
  190 DO 200 I=1,INN1
        C103(I) = VIN(INODE)
        C104(I) = C103(I)
        C101(I) = 0.
        DOIN(INODE,I) = DENSF
  200 CONTINUE
      IST = 0
      DO 201 I=INN1,NP1
       COH(INODE,I) = CZERO
       VGJH(INODE,I) = VGJ
  201 CONTINUE
      GO TO 202
 9000 DO 203 I=INN1,NP1
       COH(INODE,I) = CZ(I)
       VGJH(INODE,I) = VGZ(I)
  203 CONTINUF
  202 C104(INN1) = COH(INODE,INN1)*C103(INN1)+VGJH(INODE,INN1)
      DO 204 I=INN1,NP1
        C15(I) = DENSF/(C4*COH(INODE,I))
        C16(I) = COH(INODE,I)*RHOG/DENSF + RHOG*VGJH(INODE,I)/GO(INODE)
  204 CONTINUE
       IF(IOSUB .EQ. 0) GO TO 1002
        SBHIN(INN1) = CRIT
       IF(ISUB(INODE) .GT. 0) SBHIN(INN1) = H(1)
C
      OMGGS=.01
      DO 299 J=INN1. NP1
       JA = J + 1
       JN = J - 1
       IBUN = 1
        QFLUX = QDIS(INODE,J)*CXF(INODE)/PH(INODE)
       IF(J .GT. INN1)OMGGS=K1(INODE,JN)
       OLDOMG(I)=OMGGS
      OMAX = OLDOMG(1)
      OMIN = 0.
      IF(J .EQ. INN1) GO TO 211
       C101(J) = ALPOUT(JN)
       SBHIN(J) = SBHOUT(JN)
       DOIN(INODE,J) = DENSF - C4*C101(J)
       C103(J) = VOOUT(JN)
       C104(J) = COH(INODE,J)*C103(J) + VGJH(INODE,J)
C
  211 IF(IBUN .GT. 200) GO TO 2000
       VOOUT(J) = C103(J) + DZ(INODE,J)*OLDOMG(IBUN)
       AVGJ = (C103(J)+VOOUT(J))/2.
       A1=.04167
       CKOUT(J) = COH(INODE,J)*VOOUT(J) + VGJH(INODE,J)
       C105(J) = CKOUT(J)/C104(J)
       ALPOUT(J) = C15(J)*(1.-(1./C105(J))) + C101(J)
     1                                    *(1./C105(J))
       ALOUT(INODE,J)=ALPOUT(J)
       DOOUT(INODE,J)= DENSF - C4*ALPOUT(J)
       C107(J)  = ALPOUT(J)*C16(J)/(1.-ALPOUT(J)/C15(J))
       V1(J) = C104(J)/(COH(INODE,J)*OLDOMG(IBUN)*DZ(INODE,J))
       C108(J) = V1(J) * (C15(J)*(C105(J)-1.) +
     1          (C101(J) - C15(J))*DLOG(C105(J)))
       XAVG = C108(J)*C16(J)/(1.-C108(J)/C15(J))
       CTEMO = CO(INODE)*VFG1*(1.-XAVG)*COH(INODE,J)
       C109(J) = C104(J)/CTEMO
       C110(J) = (QFLUX*PH(INODE)*VFG1/AXS(INODE)-OLDOMG(IBUN)
     1           *(ENTHP+HFG1)) / (CTEMO*OLDOMG(IBUN)/C104(J))
       CTEM1 = -C110(J)/C109(J)
       CTEM2 = (SBHIN(J)-CTEM1) * DEXP(-C109(J))
       CTEM3 = C109(J)*C105(J)
       BTEMO(INODE,J)=CTEMO
       AVGX(INODE,J)=XAVG
       B4K(INODE,J)=CTEM1
       B5K(INODE,J)=SBHIN(J)-CTEM1
       SBHOUT(J) = CTEM2*DEXP(CTEM3) + CTEM1
       AVGH(J) = (SBHOUT(J)+SBHIN(J))/2.
       FLH=AVGH(J)*(1.-XAVG)+(HFG1+ENTHP)*XAVG
       EXPT=(FLH-CRIT)/(ENTHP-CRIT)
       CF(INODE,J)=EXP(-EXPT)
       PVGH(INODE,J)=AVGH(J)
       PHL(INODE,J)=AVGH(J)
C
      OMG = C25(INODE)*QFLUX*(AVGH(J)-CRIT)/(ENTHP-CRIT)/(RHOG*
     1         HFG1+DENSF*(ENTHP-AVGH(J))) - A1*C108(J)*
     2         (ENTHP-AVGH(J))
      EPSUB(INODE,J)=(AVGH(J)-CRIT)/(ENTHP-CRIT)*RHOG*HFG1/
     @                (RHOG*HFG1+DENSF*(ENTHP-AVGH(J)))
C
      DIFF(IBUN) = (OLDOMG(IBUN) - OMG)
      DELOMG=DIFF(IBUN)/OLDOMG(IBUN)
C
      IF(DABS(DELOMG) .LE. 5.0E-C3) GO TO 212
      IBUN2 = IBUN - 1
      IBUN1 = IBUN
      IBUN = IBUN + 1
      OLDOMG(IBUN)=OMG
      GO TO 211
C
  212  IF(C105(J)-1. .LE. 1.0E-05) GO TO 224
```

```
        K1(INODE,J) = OMG
        QO(INODE,J) = QDIS(INODE,J)*CXF(INODE)/PH(INODE)
        BEE(INODE,J) = QDIS(INODE,J) / AVEQ
        ALPIN(INODE,J) = C101(J)
        JOIN(J) = C103(J)
        CKIN(INODE,J) = C104(J)
        ZETA(INODE,J) = C105(J)
        XEXIT(J) = C107(J)
        PXEXT(INODE,J)=XEXIT(J)
        ALFNOD(INODE,J) = C108(J)
        CSB2(INODE,J) = C109(J)
        CSB3(INODE,J) = C110(J)
        GO TO 228
  224 MP1=NP1-1
      Z(INODE,INN) = Z(INODE,INN1)
      DZ(INODE,INN) = DZ(INODE,INN) + DZ(INODE,INN1)
      DO 225 I=INN1,MP1
      II = I + 1
      Z(INODE,I) = Z(INODE,II)
      DZ(INODE,I) = DZ(INODE,II)
      QDIS(INODE,I) = QDIS(INODE,II)
  225 CONTINUE
      GO TO 190
C
C     * PARAMETERS FOR THE SUBCOOLED BOILING REGION CALCULATION
C
  228 CSB4(INODE,J) = CKIN(INODE,J)*AVGJ / (COH(INODE,J)*K1(INODE,J)*
     1                DZ(INODE,J)*VFG1*GO(INODE)**2)
      CTEM4 = CTEMO*K1(INODE,J)/CKIN(INODE,J)
      CSB5(INODE,J) = VFG1*DENSF*(1.-ALFNOD(INODE,J)) / CTEM4
      CSB6(INODE,J) = (ENTHP+HFG1-CTEM1) / CTEM4
      CSB7(INODE,J) = CTEM2 / CTEM4
      CSB8(INODE,J) = CSB2(INODE,J)*CTEM2/(1.-XAVG)
      CSB9(INODE,J) = -CSB2(INODE,J)*CTEM2/GO(INODE)
      CSB10(INODE,J) = (PH(INODE)*VFG1/AXS(INODE))/CTEM4
      CSBQ(INODE,J) = (C4*PH(INODE)*QO(INODE,J)/AXS(INODE)/DENSF) /
     1                (ENTHP-CRIT)
      CSBD(INODE,J) = (AVGH(J)-CRIT)/(RHOG*HFG1+DENSF*(ENTHP-AVGH(J)))
      CSBF(INODE,J) = CSBQ(INODE,J)*(RHOG*HFG1+DENSF*(ENTHP-CRIT))
     1          /(RHOG*HFG1+DENSF*(ENTHP-AVGH(J)))**2 + A1*
     2          ALFNOD(INODE,J)/CPF
      CSBG(INODE,J) = A1*(ENTHP-AVGH(J))/CPF
      CSBE(INODE,J) = CSBQ(INODE,J)*CSBD(INODE,J)*(AVGH(J)-ENTHP)/
     1          (ENTHP-CRIT)/(AVGH(J)-CRIT)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      YSTAR(INODE,J)=(AVGH(J)-CRIT)/(RHOG*HFG1
     1             +DENSF*(ENTHP-AVGH(J))))**2
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      CSBX1(INODE) = -2.1978E-03*DH(INODE)*CPF/KF
      IF(PE .GT. 7 OE+04) CSBX1(INODE) = -1.53846E+02/GO(INODE)
      CSBX2(INODE) = 0.
      IF(PE .GT. 7.0E+04) CSBX2(INODE)=1.53846E+02*QO(INODE,INN1)
     1             *DENSF/GO(INODE)**2
      IF(IST .NE. 1) GO TO 234
      IF(J .EQ. NBB(INODE)) GO TO 301
  234 IF(ITER .EQ. 1) GO TO 300
       IF(J .EQ. 1) GO TO 230
        Z(INODE,J) = Z(INODE,JN) + DZ(INODE,J)
       GO TO 231
  230   Z(INODE,J) = DZ(INODE,J)
  231   DIFFH = SBHOUT(J) - ENTHP
       IF(ABS(DIFFH) .LE. 0.1) GO TO 250
        IF(SBHOUT(J) .GE. ENTHP) GO TO 240
       GO TO 299
C
C     * DETERMINE THE BULK BOILING POINT & NODE REDISTRIBUTION IN THE
C                TWO-PHASE REGION
C
  240 IF(IST .EQ. 1) GO TO 301
      DZBB = DZ(INODE,J)*(ENTHP-SBHIN(J))/(SBHOUT(J)-SBHIN(J))
       IF(J .EQ. 1) GO TO 241
        BBLAMB(INODE) = Z(INODE,JN) + DZBB
       GO TO 242
  241   BBLAMB(INODE) = DZBB
  242   NBB(INODE) = J
        NBB1(INODE) = J + 1
        ISU = 1
       IF(H(1) .GT. CRIT) ISU = 0
       IF(BBLAMB(INODE) .LE. 0.)BBLAMB(INODE)=0.005
      CALL ASSIGN(NBB(INODE), NP1, BBLAMB(INODE), ISU, INODE, 1)
        IBUN = 1
        OLDOMG(IBUN) = OLDOMG(1)
        ITER = 1
       GO TO 211
C
  250  BBLAMB(INODE) = Z(INODE,J)
       NBB(INODE) - J
       NBB1(INODE) = J + 1
       IMM1 = NBB1(INODE)
       IF(IMM1 .GT. NP1) GO TO 310
       GO TO 301
  299 CONTINUE
       NBB(INODE) = NP1
       NBB1(INODE) = NP1 + 1
      WRITE(6,3) SBHOUT(NP1)
      GO TO 310
C
C     * CALCULATE CHARACTERISTIC PARAMETERS IN THE TWO-PHASE REGION
C
  300   NP1 = NP1 + 1
        IMM1 = NBB1(INODE)
       GO TO 301
 1002   IMM1 = NDP1(INODE)
         BBLAMB(INODE) = CHLAMB(INODE)
  301 IF(NBB(INODE) .EQ. NP1) GO TO 311
      DO 302 I=IMM1,NP1
       INM1 = I - 1
      Z(INODE,I) = Z(INODE,INM1) + DZ(INODE,I)
  302 CONTINUE
      DO 303 I=IMM1,NP1
        IN = I - 1
        AVGH(I) = ENTHP
        PVGH(INODE,I)=AVGH(I)
        C15(I) = DENSF/(C4*COH(INODE,I))
        C16(I) = COH(INODE,I)*RHOG/DENSF+RHOG*VGJH(INODE,I)/GO(INODE)
        QO(INODE,I) = QDIS(INODE,I)*CXF(INODE)/PH(INODE)
        BEE(INODE,I) = QDIS(INODE,I) / AVEQ
        K1(INODE,I) = PH(INODE)*QO(INODE,I)*VFG1/(AXS(INODE)*HFG1)
        IF(IOSUB .EQ. 0 .AND. I .EQ. IMM1) GO TO 304
        JOIN(I) = VOOUT(IN)
      CKIN(INODE,I) = COH(INODE,I)*JOIN(I) + VGJH(INODE,I)
      ALPIN(INODE,I) = ALPOUT(IN)
      DOIN(INODE,I) = DENSF - C4*ALPIN(INODE,I)
       GO TO 305
 304  JOIN(I) = VIN(INODE)
      CKIN(INODE,I) = COH(INODE,I)*JOIN(I) + VGJH(INODE,!)
      ALPIN(INODE,I) = 0.
 305  VOOUT(I) = JOIN(I) + DZ(INODE,I)*K1(INODE,I)
      CKOUT(I) = COH(INODE,I)*VOOUT(I) + VGJH(INODE,I)
      ZETA(INODE,I) = CKOUT(I) / CKIN(INODE,!)
      ALPOUT(I) = C15(I)*(1.-1./ZETA(INODE,I)) + ALPIN(INODE,I)/
     1                    ZETA(INODE,I)
      ALOUT(INODE,I)=ALPOUT(I)
      DOOUT(INODE,I)= DENSF - C4*ALPOUT(I)
      V1(I) = CKIN(INODE,I) / (COH(INODE,I)*K1(INODE,I)*DZ(INODE,I))
      ALFNOD(INODE,I) = V1(I) * (C15(I)*(ZETA(INODE,I)-1.) +
     1        (ALPIN(INODE,I) - C15(I))*ALOG(ZETA(INODE,I)))
      XEXIT(I)=ALPOUT(I)*C16(I)/(1.-COH(INODE,I)*C4*ALPOUT(I)/DENSF)
      PXEXT(INODE,I)=XEXIT(I)
 303 CONTINUE
 310 CONTINUE
 311 IF(ICAL .GT. 0 .AND. ICAL .LT. 4) GO TO 390
     IF(IRW .EQ. 0) GO TO 312
     IF(IWIT .LE. 1) GO TO 390
 312 IFILE = IST + 1
     IF(IST .EQ. 0) WRITE(IFILE,5)
     IF(IST .EQ. 1) WRITE(IFILE,7)
     DO 320 I=INN1,NP1
C     ZAXIS = (Z(INODE,I)-DZ(INODE,I)/2.)*30.48
      ZAXIS = Z(INODE,I)-DZ(INODE,I)/2.
      XEQM = (ENTHT-ENTHP+QFLUX*PH(INODE)*ZAXIS/AXS(INODE)
     1         /GO(INODE)) / HFG1
      WRITE(IFILE,9) XEQM, ALFNOD(INODE,I)
 320 CONTINUE
 390 IF(ISLIP .EQ. 0) GO TO 500
     IF(IST .EQ. 1) GO TO 500
C
C    * Determine CO & Vgj for each node with Okawa & Lahey model
C
     PCO = RHOG / DENSF
     PC1 = SQRT(PCO)
     XC1 = 0.588116 - 1.81701*FC1 + 2.00025*PC1**2 - 3.34398*PC1**3
     YCO = 4.72085 - 17.26736*PC1 + 56.14883*PC1**2 + 113.216*PC1**3
    1     - 1250.603*PC1**4 + 3039.767*PC1**5 - 2431.823*PC1**6
     YC1 = AMAX1(YCO,3.136)
     VGJO = (32.2*G1*SIGM*C4)**0.25 / SQRT(DENSF)
     VGJ1 = 2.9*VGJO
     DO 400 I=INN1,NP1
     VGJ2 = YC1*VGJO*(1.-((ALFNOD(INODE,I)-XC1)/(1.-XC1))**2)
     COO = -18.*ALFNOD(INODE,I)
     CO1 = (1.2-0.2*PC1) * (1.-EXP(COO))
     CO2 = 1.+0.2*(1.-PC1)*(1.-((ALFNOD(INODE,I)-XC1)/(1.-XC1))**2)
     IF(ALFNOD(INODE,I) .GE. XC1) GO TO 401
      VGZ(I) = VGJ1
      CZ(I) = CO1
     GO TO 400
 401  VGZ(I) = AMIN1(VGJ1,VGJ2)
      CZ(I) = AMIN1(CO1,CO2)
 400 CONTINUE
     ITER = 0
```

```
      IST = 1
      GO TO 9000
C
  500 NTOT(INODE) = NP1
      IF(IOSUB .EQ. 0)GO TO 626
      NBM1=NBB(INODE)
      XTEMO=GO(INODE)*VFG1*(1.-XEXIT(NBM1))*COH(INODE,NBM1)
      BSB2=CKOUT(NBM1)/XTEMO
      B110=(QO(INODE,NBM1)*PH(INODE)*VFG1/AXS(INODE)-
     @      K1(INODE,NBM1)*(ENTHP+HFG1))/(XTEMO*K1(INODE,NBM1)/
     @      CKOUT(NBM1))
      BTEM1=-B110/BSB2
      BTEM2=(SBHIN(NBM1)-BTEM1)*EXP(-BSB2)
      THETAB=-K1(INODE,NBM1)*COH(INODE,NBM1)/(CKIN(INODE,NBM1)*
     @        BSB2*BTEM2)*EXP(-BSB2)
  626 CONTINUE
C
C    * CHANNEL EXIT PARAMETERS
C
      XCHOUT(INODE) = XEXIT(NP1)
      CCHOUT(INODE) = CKOUT(NP1)
      ACHOUT(INODE) = ALPOUT(NP1)
      DO 501 I=INN1,NP1
        AVQT = C16(I)*ALFNOD(INODE,I)/(1.-ALFNOD(INODE,I)/C15(I))
       IF(IPILO .LT. 1) GO TO 502
        CPI1(INODE,I) = DD1*AVQT**(-0.176)/(VFG1*DENSF)
        CPI2 = 1.
       GO TO 503
  502   CPI1(INODE,I) = CHOMO1
        CPI2 = CHOMO2
  503   C8(INODE,I) = (CPI2-CPI1(INODE,I)) - CPI1(INODE,I)*DENSF*
     1       VGJH(INODE,I)/(COH(INODE,I)*GO(INODE))
        C9(INODE,I) = (CPI1(INODE,I)*DENSF) * (1.+DENSF*VGJH(INODE,I)/
     1       (COH(INODE,I)*GO(INODE))) / (DENSF - COH(INODE,I)*C4*
     2       ALPIN(INODE,I))
        COR2PH(INODE,I) = C8(INODE,I) + C9(INODE,I)*(ZETA(INODE,I)+1)
     1               /2.
  501 CONTINUE
       IF(IRW .EQ. 0) GO TO 505
       IF(IWIT .LE. 1) GO TO 604
  505 C21(INODE) = K1(INODE,INN1)/(RHOG*VFG1*CKIN(INODE,INN1))
       IF(ISUB(INODE) .GT. 0) C21(INODE) = 0.
      C6 = (GO(INODE)*VIN(INODE)/CKIN(INODE,INN1)) * (1./GC)
      C7 = DENSF*RHOG*(VGJH(INODE,INN1)+(COH(INODE,INN1)-1.)*VIN(INODE)
     1       )**2 / (C4*CKIN(INODE,INN1)) * (1./GC)
      C22(INODE) = (C6+C7)*K1(INODE,INN1) + C2(INODE)
C
C    * CALCULATE WALL & BULK TEMPERATURE WITH ASSUMING THAT THE BULK
C             TEMPERATURE IN THE TWO-PAHSE REGION IS TSAT
C
      T1 = TIN
      IF(H(1) .GT. CRIT ) GO TO 510
       INN = NDP(INODE)
      DO 511 I=1,INN
      TLIQ(I) = T1 + QO(INODE,I)*PH(INODE)*(DZ(INODE,I)/2.)
     1          /(CPF*GO(INODE)*AXS(INODE))
      TWALL(I) = TLIQ(I) + QO(INODE,I)/HO(INODE)
      T1 = TLIQ(I)
  511 CONTINUE
C
```

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  510 DO 520 I=INN1,NP1
      TLIQ(I) = TSATP
       IF(IOSUB .EQ. 0) GO TO 1003
       IF(IOSUB .EQ. 1 .AND. I .LT. NBB1(INODE)) GO TO 521
       GO TO 1003
  521 CONTINUE
      TL = TSATP - (ENTHP-AVGH(I))/CPF
      TLIQ(I) = TL
 1003 TWALL(I) = TSATP + (QO(INODE,I)/CKI)**(1./CMP)
      V22(INODE,I) = CKI*CMP*(TWALL(I)-TSATP)**(CMP-1.)
  520 CONTINUE
C
      VEX = JOIN(NP1) + DZ(INODE,NP1)*K1(INODE,NP1)
  604 ALFSUM = 0.
      DO 530 I=INN1,NP1
  530 ALFSUM = ALFSUM + ALFNOD(INODE,I)*DZ(INODE,I)
      CHALF = ALFSUM/ALHEAT
C
C     * CHECK NODES WHICH INCLUDE SPACER
C         NUMBSP(I,J) ; THE NUMBER OF SPACERS INTHE (I,J)-TH MODE  )
C
      DO 550 I=1,NP1
      NUMBSP(INODE,I) = 0
  550 CONTINUE
C
      IF(NSP .EQ. 0) GO TO 600
      KSP = 1
      I = 0
  551 I = I + 1
      IF(I .GT. NP1) GO TO 552
      IF(ZSP(KSP) - Z(INODE,I) .GT. 1.0E-03) GO TO 551
  553 NUMBSP(INODE,I) = NUMBSP(INODE,I) + 1
      KSP = KSP + 1
      IF(KSP .GT. NSP) GO TO 552
      IF(ZSP(KSP) .GT. Z(INODE,I)) GO TO 551
      GO TO 553
  552 CONTINUE
C
C     * PARAMTERS TO CALCULATE THE LOCAL PRESSURE DROP IN THE SINGLE-
C                 & THE TWO-PHASE REGION
C        N1PSP(I) ; THE TOTAL NUMBER OF SPCERS IN THE SINGLE-PHASE REGION
      N1PSP(INODE) = 0
       IF(ISUB(INODE) .GT. 0) GO TO 560
      DO 561 I=1,INN
  561 N1PSP(INODE) = N1PSP(INODE) + NUMBSP(INODE,I)
  560 K2PSP(INODE) = N1PSP(INODE) + 1
C
      K2HSP = N1PSP(INODE) + 1
      DO 570 K=INN1,NP1
      KK = K - 1
      NNSP = NUMBSP(INODE,K)
      IF(NNSP .EQ. 0) GO TO 570
      IF(ISUB(INODE) .GT. 0 .AND. K .EQ. INN1) GO TO 571
      DO 572 N=1,NNSP
      DELSZ = ZSP(K2HSP) - Z(INODE,KK)
      CKSP(K2HSP) = CKIN(INODE,K) + DELSZ*COH(INODE,K)*K1(INODE,K)
      ZETSP(INODE,K2HSP) = CKSP(K2HSP) / CKIN(INODE,K)
  572 K2HSP = K2HSP + 1
      GO TO 570
C
```

```
  571 DO 573 N=1,NNSP
      CKSP(K2HSP) = CKIN(INODE,K) + ZSP(K2HSP)*COH(INODE,K)*K1(INODE,K)
      ZETSP(INODE,K2HSP) = CKSP(K2HSP) / CKIN(INODE,K)
  573 K2HSP = K2HSP + 1
  570 CONTINUE
C
C     * CALCULATE STEADY-STATE PRESSURE DROPS . . . . . . . . . . . . .
C                            ACCL    FRIC    GRAV     LOCAL  SPACER   TOTAL
C      1) SINGLE-PHASE;            DPH1PF  DPH1PG     DPIN  DP1HSP  DP1HP
C      2) TWO-PH.(NODE);DPH2PA     DPH2PF  DPH2PG   DPEXIT    DPSP
C         TWO-PH.(TOTAL); DP2A       DP2F    DP2G             DP2HSP   DP2T
C
C     * 1) SINGLE-PHASE REGION
  600 DPIN = XKIN(INODE)*G02RF(INODE)
      DP1HSP = DPIN
      DPH1P = 0.
      DPH1PG = 0.
      DPH1PF = 0.
      IF(ISUB(INODE) .GT. 0) GO TO 701
      INNSP = N1PSP(INODE)
      IF(INNSP .EQ. 0) GO TO 605
      DO 700 I=1,INNSP
      DPSP(I) = KLOSS(I)*G02RF(INODE)
      DP1HSP = DP1HSP + DPSP(I)
  700 CONTINUE
C
  605 DPH1PG = DENSF*CHLAMB(INODE)*G1/GC
      DPH1PF = FRICMO(INODE)*CHLAMB(INODE)*G02RF(INODE)/DH(INODE)
      DPH1P = DPH1PG + DPH1PF
C     * 2) TWO-PHASE REGION
  701 DP2G = 0.
      DP2F = 0.
      DP2A = 0.
      DP2T = 0.
      DO 710 I=INN1,NP1
      IF(ZETA(INODE,I)-1. .LE. 1.0E-04) GO TO 702
      C19 = (G1/GC)*DZ(INODE,I)*DENSF*(1.-1./COH(INODE,I))
      C20 = (G1/GC)*(CKIN(INODE,I)/COH(INODE,I)/K1(INODE,I))*(DENSF/
     1          COH(INODE,I)-C4*ALPIN(INODE,I))
      DPH2PG(I) = (C19 + C20*ALOG(ZETA(INODE,I)))
      GO TO 703
  702 DINO = DENSF-C4*ALPIN(INODE,I)
      DPH2PG(I) = DINO*DZ(INODE,I)*G1/GC
  703 DP2G = DP2G + DPH2PG(I)
      DPH2PF(I) = V7(INODE)*DZ(INODE,I)*COR2PH(INODE,I)
      DP2F = DP2F + DPH2PF(I)
      IF(I .EQ. INN1) GO TO 711
      II = I - 1
      RHOIN = (1.-XEXIT(II))**2/((1.-ALPIN(INODE,I))*DENSF) +
     1          XEXIT(II)**2/(RHOG*ALPIN(INODE,I))
      GO TO 712
  711 RHOIN = 1./DENSF
  712 RHOOUT = (1.-XEXIT(I))**2/((1.-ALPOUT(I))*DENSF) + XEXIT(I)**2
     1          /(RHOG*ALPOUT(I))
      DPH2PA(I) = (G02(INODE)/GC)*(RHOOUT - RHOIN)
      DP2A = DP2A + DPH2PA(I)
      DPH2P(I) = DPH2PG(I) + DPH2PF(I) + DPH2PA(I)
      DP2T = DP2T + DPH2P(I)
  710 CONTINUE
C
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      DP2HSP = 0.
      KNSP = N1PSP(INODE)
      DO 720 I=INN1,NP1
      II = NUMBSP(INODE,I)
      IF(II .EQ. 0) GO TO 720
      DO 721 K=1,II
      KNSP = KNSP + 1
      DPSP(KNSP) = (KLOSS(KNSP)*G02(INODE)/(2.*GC*DENSF)) *
   1              COR2PH(INODE,I)
  721 DP2HSP = DP2HSP + DPSP(KNSP)
  720 CONTINUE
      DPEXIT = XKEXIT(INODE)*G02(INODE)/(2.*GC*DENSF)*COR2PH(INODE,NP1)
      DP2HSP = DP2HSP+DPEXIT
C
      DPHT = DPH1P + DP2T
      DPTS = DP1HSP+ DPHT + DP2HSP
      IF(IRW .EQ. 0) GO TO 800
      IF(IWIT .LE. 1) GO TO 4000
C
C ***** PRINT OUT FOR CHANNEL CHARECTERISTICS IN STEADY-STATE *****
C
  800 IF(ICH.NE.3 .AND. ICH.NE.6) GO TO 802
      WRITE(6,11)INODE,AXS(INODE),PH(INODE),DH(INODE),BBLAMB(INODE)
     1 CXF(INODE),VIN(INODE),XKIN(INODE),XKEXIT(INODE),RPWR(INODE)
      IF(ICAL .LE. 1) GO TO 801
      IF(ICAL .EQ. 4) GO TO 801
C
  801 WRITE(6,41)
      IF(IOHW .EQ. 0) WRITE(6,43)
      IF(IOHW .EQ. 1) WRITE(6,45) CPH, DENSH
      IF(IOHW .EQ. 2) WRITE(6,47) CPH, TKH, DENSH
      IF(IOHW .EQ. 3) WRITE(6,49) CPH, TKH, DENSH, CRI, CRO
      IF(IOHW .EQ. 4) WRITE(6,51) CPH,TKH,DENSH,CRS, CPC,TKC,
     1                             DENSC,CRI,CRO, GAPC
  802 IF(ICH.NE.4 .AND. ICH.NE.6) GO TO 821
C
      WRITE(6,57)
      DO 820 I=1,NP1
      IF(I .EQ. INN1) WRITE(6,59)
  820 WRITE(6,61)I,Z(INODE,I),QO(INODE,I),QDIS(INODE,I),TLIQ(I),
     @           TWALL(I)
  821 IF(ICH.LE.1 .OR. ICH.EQ.3) GO TO 831
      IF(NODES .EQ. 1) GO TO 831
      WRITE(6,67)
      DO 830 I=INN1,NP1
      WRITE(6,69) I,DZ(INODE,I),K1(INODE,I),COH(INODE,I),VGJH(INODE,I),
     1            ALFNOD(INODE,I),XEXIT(I),AVGH(I), JOIN(I)
  830 CONTINUE
  831 IF(ICH.EQ.0 .OR. ICH.EQ.2 .OR. ICH.EQ.3) GO TO 4000
      WRITE(6,71)
      ZIN = 0.0000
      WRITE(6,73) ZIN, XKIN(INODE), DPIN
      DO 840 I=1,NSP
      WRITE(6,73) ZSP(I), KLOSS(I), DPSP(I)
  840 CONTINUE
      WRITE(6,73) ALHEAT, XKEXIT(INODE), DPEXIT
C
      IF(H(1) .GT. CRIT) GO TO 850
      WRITE(6,75) DP1HSP,DPH1PG,DPH1PF,DPH1P
  850 WRITE(6,77)
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      DO 860 I=INN1,NP1
      WRITE(6,79) I, Z(INODE,I), DPH2PG(I),DPH2PF(I),COR2PH(INODE,I),
     1              DPH2PA(I), DPH2P(I)
  860 CONTINUE
      WRITE(6,81) DP2G, DP2F, DP2A, DP2T, DP2HSP, DPTS
      GO TO 4000
C
 2000 WRITE(6,85)
      STOP
C
 4000 RETURN
      END
C
C
C
C
C********************************************************************
      SUBROUTINE XLOOP(ICAL,JLL,JRR,IPUMP,IRSLIP)
C********************************************************************
C
C     * CALCULATE THE STEADY-STATE PARAMETERS OF THE LOOP ANALYSIS
C
      REAL MUTL, KF, KLOSS
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMPLEX CLTX,RR4
      COMPLEX CSBX3, DGAMP,VPL
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      COMMON/OPTION/ IOSUB, IOHW, IO2Q, IPILO, ISLIP, IRW
      COMMON/CONST1/ C1(5),C2(5),C3(5),C4,C5(5),C8(5,30),
     1       C9(5,30),C18(5), C21(5), C22(5),C25(5),
     2       C26(5), T6, V7(5), DD1, CKI, CMP
      COMMON/CONST2/ P,VCH,VIN(5),AXS(5),DH(5),DHIN(5),
     1       PH(5),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2       DENSF,VFG1,RHOG,GO(5),GO2(5),HO(5),GC,G1,KLOSS(30),
     3       FRICHO(5),VGJH(5,30),COH(5,30),CZERO,VGJ,DPTS,
     4       GO2RF(5),HFG1,ZSP(30),NUMBSP(5,30),ALHEAT,CXF(5),
     5       AVEQ,CHOMO1,CHOMO2,XKIN(5),XKEXIT(5)
      COMMON/CONSS1/ QDIS(5,30), QO(5,30), DZ(5,30),Z(5,30),
     1       K1(5,30), CKIN(5,30), ZETA(5,30), DOIN(5,30),
     2       DOOUT(5,30), ALPIN(5,30),BEE(5,30), CPI1(5,30),
     3       COR2PH(5,30), ZETSP(5,30), WIN
      COMMON/PCHOUT/XCHOUT(5), ACHOUT(5), CCHOUT(5)
      COMMON/CONSS2/ NTOT(5),NBB(5),NBB1(5),NSP,N1PSP(5),
     1               K2PSP(5), NDP(5), NDP1(5), ISUB(5)
      COMMON /RISER/ COR,VGJR,CKRO,RL,AR,DRIN,DR,PI,CL1,CL2,CL3,CL4,
     1       CL5,CL6,CR5,CR6,UPJ1(5),UPJ2(5),RO11,RO12,
     2               RO21, RO22, XROUT, UPJIN
      COMMON/CLOOP/SLOOP,SFLOOP,RLOOP,AA,
     @              VL1(5), VL2(5), VL3(5), DPLPT,RATW
      COMMON/CUPPER/RKIN,RKEXIT,AP,RPO,RP1,RP2,CL10(5),CL11(5),
     1               CLT,AXSCH,RAR,AD,DL,DHDL,FDL, F1(5),F2(5),
     2               RJ1(5),RJ2(5),RJ3(5),F3(5)
      COMMON /CDELH1/ HFW, ADC, PHV, DKV, CPV, DENV, TEMV, TEMINV,
     1               THV, HOD, PLM, AHLP, THLP, HOLP, WO, DLENG
      COMMON /CDELH2/ CH1, CH2, CH3, CH4, CH5, CH7, CH8, CH9, CH10
      COMMON /XVXV/ XVL1,XVL2,XVL3
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMMON/RISERP/CLTX,RR4,CRP5,CRP8,RO13,RO23,CL12,UPJ3,ALPRO
     1              ,GOR,RHOR,VRO,CRCON,UPALP
      COMMON/SWITCH/IDCZC,IDVGJC,IDCZR,IDVGJR
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      COMMON/PXX/PXEXT(5,30)
      COMMON/PSP/CSBX3(5,30),ALOUT(5,30)
      COMMON/YYY/ZLUP,FLUP,GOU,DHUP,ROUP,FUP,ZLR,FLR,ROR,FRR
     @           ,ADLP,DHLP,ZLLP,FLLP,XKLP,GOLP,FLP
     @           ,AD1,DH1,ZL1,FL1,XK1,GO1,FD1
     @           ,AD2,DH2,ZL2,FL2,XK2,GOD2,FD2
     @           ,AD3,DH3,ZL3,FL3,XK3,GO3,FD3
     @           ,SPUMP,CPUMP
      COMMON/SEPA/XINER,XLSEP,XKSEP,XASEP,XRHOS,ALPSEP,GOSEP,
     @              YLSEP,DHSEP,FSEP,CSEP,VSEP,CORPR
      COMMON/DELTAP/DGAMP,DRHOG,DHF,DHG,DCZERO,DVGJ,DCOR,DVGJR
      COMMON/PIV/IV
      COMMON/VV4/PL1,PL2,PL4
      COMMON/VV5/VPL
      COMMON/PGAM/IGAM,IDRF
      COMMON/PCO/ICO
      COMMON/RNEW/F3P,RW3P
      COMMON/MULT/NN(5)
      COMMON/MULTW/UPJW(5),CLW(5),PJOUT(5)
      COMMON/PBB/POWER,BYPOWF,BYFLWF
C   QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
   15 FORMAT(//5X,'PARAMETERS FOR THE UPPER PLENUM', //10X,
     1         'FLOW AREA',6X,'LENGTH I', 6X,'LENGTH II',
     2          6X,'CURVATURE',6X,'HYDR. DIAM.')
   17 FORMAT(/9X, F9.4, 4(6X,F9.4) )
   19 FORMAT(/10X,'VOID FRACTION =',E10.4, 'VO,UP =',E10.4 )
   21 FORMAT(//5X,'PARAMETERS FOR THE RISER', //10X,' LENGTH  ',
     1        6X,'FLOW AREA', 5X,'HYDR.DIAM.', 9X,'CO', 12X,'VGJ')
   23 FORMAT(/9X,F9.4, 4(6X,F9.4) )
   25 FORMAT(/10X,'GO,R =',E10.4, 5X,'VO,R =',E10.4, 5X,
     1         'VOID FRACTION =',E10.4, /10X,'CORPR =',E10.4 )
   27 FORMAT(//5X,'PARAMETERS FOR THE LOOP',  //10X,'  SLOOP  ',
     1        8X,'SFLOOP', 11X,'AA')
   29 FORMAT(/4X, 2(5X,E10.4),5X,E10.4)
   31 FORMAT(//5X,'PARAMETERS FOR DOWNCOMER ENTHALPY DYNAMICS',
     @        //7X,'F.W. ENTH',
     1          6X,'FLOW AREA', 7X,'LENGTH',15X,'VESSEL TEMPS',
     2         15X,'PH',13X,'HO' )
   33 FORMAT(/2X, 7(5X,E10.4) )
   35 FORMAT(//20X,'VESSL WALL', /20X,'THICKNESS(FT)  =',3X,E10.4,
     1         /20X,'THERMAL CONDUTIVITY  =',3X,E10.4,
     2         /20X,'SPECIFIC HEAT  =',3X,E10.4,
     3         /20X,'DENSITY(LB/FT3)  =',3X,E10.4)
   37 FORMAT(/10X,'WO(LB/S)  =',3X,E10.4, 10X,'ENTH. MIX.  =',3X,E10.4,
     1         10X,'ENTH. DC(EXIT)  =',3X,E10.4)
   39 FORMAT(//5X,'PARAMETERS FOR LOWER PLENUM', //7X,
     1         'COOLANT MASS(LB)',1X,'H/T AREA', 10X,'HO',
     2         10X,'THICK', 9X,'HEAT FLUX')
C
C     * CALCULATE THE INLET PARAMETERS OF THE UPPER PLENUM
C        XUPI ; INLET FLOW QUALITY
C        UPALP ; INLET VOID FRACTION
C        UPJIN ; INLET FLOW VELOCITY
C
      DRF=DRFDP(P)
      IF(IDRF .EQ. 0)DRF=0.
      DDR=DRHOG-DRF
      DRGFP=DRHOG-RHOG/DENSF*DRF
      B10 = 0.
      DO 10 I=JLL,JRR
      B10 = B10 + XCHOUT(I)*GO(I)*AXS(I)*NN(I)
   10 CONTINUE
      WBYP=BYFLWF*WO
      SUBC=HF(P)-ENTHT
      XUPI = B10/WO-(WBYP*SUBC-BYPOWF*POWER)/(HFG1*WO)
      UPALP = XUPI*DENSF/(RHOG+C4*XUPI)
      P2 = DENSF - C4*UPALP
      UPJIN = WO/AP/P2
      UPJOUT = (AP/RAR)*UPJIN
      F = DENSF*RHOG/(RHOG+C4*XUPI)**2
      GOP = UPJIN*P2
      SUMF3P=0.
      SUMJ3P=0.
      SUM1=0.
      SUM12=0.
      DO 11 I=JLL,JRR
      NP1 = NTOT(I)
      E1 = -RHOG*VGJH(I,NP1)*DENSF*ACHOUT(I)/GO(I)**2
      E2 = (RHOG*COH(I,NP1)/DENSF + RHOG*VGJH(I,NP1)/GO(I) +
     1       C4*COH(I,NP1)*XCHOUT(I)/DENSF + C4*RHOG*VGJH(I,NP1)*
     2       ACHOUT(I)*CCHOUT(I)/GO(I)**2) / (1.-C4*COH(I,NP1)*
     3       ACHOUT(I)/DENSF)
        F1(I) = F*AXS(I)*GO(I)*E1/WO
        F2(I) = F*AXS(I)*GO(I)*E2/WO
        F3(I) = F*(XCHOUT(I)-XUPI) /WO
        RJ1(I)=(C4*UPJIN*F1(I)+AXS(I)*(DENSF-C4*COH(I,NP1)*ACHOUT(I))
     1           /AP) / P2
        RJ2(I) = (C4*UPJIN*F2(I)-AXS(I)*C4*CCHOUT(I)/AP) / P2
        RJ3(I) = C4*UPJIN*F3(I) / P2
      WW=GO(I)*AXS(I)/WO
      CZERO=COH(I,NP1)
      VGJ=VGJH(I,NP1)
      P1=CZERO*RHOG/DENSF+RHOG*VGJ/GO(I)
      CL7 = P1 + CZERO*C4*XCHOUT(I)/DENSF
     1 + (C4*RHOG*VGJ/GO(I)**2)*ACHOUT(I)*CCHOUT(I)
      CL8 = (RHOG + C4*XCHOUT(I)) /DENSF
      CL9 = P2 / (DENSF-CZERO*C4*ACHOUT(I))
      CL10(I) = (CL7/CL8) * CL9*WW
      CL11(I) = -(VGJ*RHOG*DENSF*ACHOUT(I)*(P2/DENSF)) /
     1          (CL8*GO(I)**2)*WW
      CLW(I)=(XCHOUT(I)-XUPI)/(WO*(CL8*DENSF/P2))
      UPJW(I)=C4*UPJIN*CLW(I)/P2
      UPJ1(I) = ((AXS(I)/AP)*(DENSF-C4*CZERO*ACHOUT(I))
     1             + C4*UPJIN*CL11(I)) /P2
      UPJ2(I) = (C4*UPJIN*CL10(I)- (AXS(I)/AP)*C4*CCHOUT(I)) / P2
C ADD J3 AND F3 TO CODE
      PJOUT(I)=(CCHOUT(I)-VGJ)/CZERO
      CP3=ACHOUT(I)*RHOG/GO(I)*(1+ACHOUT(I)*C4*VGJ
     1    /GO(I))*DVGJ
      CP3=CP3+ACHOUT(I)*CZERO/DENSF*DRF*(XCHOUT(I)-RHOG/DENSF)
      CP2=ACHOUT(I)/DENSF*(RHOG+XCHOUT(I)*C4+ACHOUT(I)*PJOUT(I)
     1    *RHOG*DENSF*C4*VGJ/GO(I)**2)*DCZERO
      CP1=ACHOUT(I)*(CZERO/DENSF*(XCHOUT(I)-1)
     1    -VGJ/GO(I)*(1-RHOG*ACHOUT(I)*CCHOUT(I)
     2     /GO(I)))*DRHOG
      CL12=-(CP1-CP2-CP3)*DENSF/P2
      SUM12=SUM12+CL12*WW*NN(I)
      UPJ32=AXS(I)/AP*(ACHOUT(I)*CCHOUT(I)*DDR-ACHOUT(I)*C4*
     @       (DCZERO*PJOUT(I)+DVGJ)+PJOUT(I)*DRF)
```

```
      SUM1=SUM1+UPJ32*NN(I)
      UPJ31=DDR*UPALP*UPJIN+DRF*UPJIN
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
   11 CONTINUE
      CP4=-(UPALP*DRHOG/DENSF*(XUPI-1.)-UPALP/DENSF*DRF*(XUPI-
     @      RHOG/DENSF))*DENSF/P2
      CL12=SUM12-CP4/(CL8*DENSF/P2)
      UPJ33=C4*UPJIN*CL12
      UPJ3=(UPJ33+SUM1-UPJ31)/P2
C
      DRP = RP2 - RP1
      CLTX = 0.
      IF(RPO .EQ. 0.) GO TO 12
      CLTX = AP*DRP + (PI*RPO-AP/RPO)*(RP2**2-RP1**2)/2.
     1              - PI*(RP2**3-RP1**3)/3.
   12 CLT = (RP1 - ALHEAT + CLTX/AP) /UPJIN
C
C     INLET PARAMETERS IN THE RISER
C
      IF(IRSLIP .NE. 0)GO TO 77
      TAVE=(TIN+TSATP)/2.
      SIGMA=SGMA(P,TAVE)
      COR=1.2-0.2*SQRT(RHOG/DENSF)
      VGJR=2.9*(C4*SIGMA*G1*32.2/DENSF**2)**.25
   77 CONTINUE
      GOR = (AP/RAR)*GOP
      XROUT = XUPI
      ALPRO = XROUT/(RHOG*VGJR/GOR+COR*RHOG/DENSF*(1.+XROUT
     @        *C4/RHOG))
      CL2 = DENSF - C4*COR*ALPRO
      VRO = (GOR+C4*VGJR*ALPRO)/(DENSF-C4*COR*ALPRO)
      CKRO=COR*VRO+VGJR
      IF(IPILO .EQ. 0) GO TO 13
      RPI1 = DD1*XROUT**(-0.176)/(VFG1*DENSF)
      RPI2 = 1.
      GO TO 14
   13 RPI1 = CHOMO1
      RPI2 = CHOMO2
   14 CORPR = RPI2 + RPI1*VFG1*DENSF*XROUT
      RHOR = DENSF - C4*ALPRO
      DR = DRIN/12.0
      C1R = -1.41E-05*DRIN + 3.36E-04
      VISR = MUTL(TSATP)/3600.0
      RER = GOR*DR/VISR
      FRICR = 0.0055*(1. + (20000.*C1R+1.0E+06/RER)**(1./3.))
      RC1 = (RHOG + C4*XUPI) / P2
      RC2 = COR*RHOG/DENSF + RHOG*VGJR/GOR + COR*C4*XROUT/DENSF
     1      + C4*RHOG*VGJR*ALPRO*CKRO/GOR**2
      RC3 = RC2 / (CL2/DENSF)
      RC4 = -RHOG*DENSF*VGJR*ALPRO/GOR**2
      ROD = C4*CKRO*RC4 + CL2*RC3
      RO11 = (P2*RC3/ROD) * (AP/RAR)
      RO12 = (C4*CKRO*RC1 - C4*UPJOUT*RC3) / ROD
      RO21 = -(P2*RC4/ROD) * (AP/RAR)
      RO22 = (C4*UPJOUT*RC4 + CL2*RC1) / ROD
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      CL1 = (FRICR*GOR*CORPR) / (GC*DENSF*DR)
      CL3 = (FRICR*GOR/(2.*GC*DR)) * (1.-VRO*CL2/GOR) *  RPI1
      CL4 = - (FRICR*VRO*C4*CKRO**2) / (2.*GC*DR) * RPI1
      CL5 = -2.*(GOR/RHOR)*C4*CKRO + C4*(GOR/RHOR)**2
      CXX = DENSF*RHOG * ((COR-1.)*VRO+VGJR)**2
     1            /  (RHOR**2 - RHOG*RHOR)**2
      CL6 = CXX * (2.*DENSF*RHOR - RHOR**2 - RHOG*DENSF) * C4
      CRCON = (GOR*CORPR/DENSF - RPI1*VRO/2.) / GC
      CR5 = CRCON*CL2 + GOR*RPI1/(2.*GC)
      CR6 = -C4*CKRO*CRCON
      CH1 = -RAR/VFG1 + (RAR*DENSF/C4)*CL2
      CH2 = RAR*CKRO*DENSF
      WSWO = WO*(1.-XROUT)
      CH9 = FDL*WSWO**2/(2.*GC*DHDL*AD**2*DENSF) - (G1/GC)*DENSF
      CH10 = DL*FDL*WSWO/(GC*DHDL*AD**2*DENSF)
C
C       3) FOR THE SINLE-PHASE LOOP
C
      XVL1 = SLOOP/GC * RATW
      XVL2 = (WO/DENSF)*SFLOOP / GC * RATW
      XVL3 = AA * RATW
C
C     * CALCULATE THE S.S PRESSURE DROP IN THE EXT. LOOP
C
C       1) FOR THE UPPER PLENUM
           DPUPL = (G1/GC)*P2*(RP2-ALHEAT)
C       2) FOR THE RISER
           DPR =((RHOR+CL1*GOR/2.)*(RL-RP2)*G1/GC+(RKIN+RKEXIT)*
     1                GOR**2*CORPR/(2.*GC*DENSF) )
C       3) FOR THE LOOP
           DPLOOP = SFLOOP*(WO**2/2./GC/DENSF)
C       * TOTAL P.D. IN THE EXT. LOOP
           DPLPT = DPUPL + DPR + DPLOOP
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C     * II) EXTERNAL LOOP
C     *  1) UPPER PLENUM I & II
      WCORE=WO
      ROUP=DENSF*(1.-UPALP)+RHOG*UPALP
      GOU=ROUP*UPJIN
      DHUP=SQRT(4.*AP/3.1416)
      XU=-1.41E-05*DHUP*12.+3.36E-04
      YU=GOU*DHUP/VISC
      FUP=.184/(2.*DHUP*YU**0.2)
      DPUF=GOU**2/(2.*GC*ROUP)*FLUP/DHUP*FUP
      DPUG=G1/GC*ROUP*(ZLUP+DRP)
      SIGUP=AP/AR
C
      DPUL=0.
      DPU=DPUF+DPUG+DPUL
C     *  2) RISER
      ROR=DENSF*(1.-ALPRO)+RHOG*ALPRO
      XR=-1.41E-05*DRIN+3.36E-04
      YR=GOR*DRIN/12./VISC
      FRR=.184/(2.*DR*YR**0.2)
      DPRF=GOR**2/(2.*GC*ROR)*FLR/(DRIN/12.)*FRR
      DPRG=G1/GC*ROR*ZLR
      DPRL=RKEXIT*GOR**2/(2.*GC*ROR)
      DPR=DPRF+DPRG+DPRL
C     *  3) STEAM SEPARATOR
      XRHOS=RHOR
      ALPSEP=ALPRO
      GOSEP=GOR
      FSEP=FRR
      VSEP=VRO
      XS=-1.41E-05*DHSEP*12.+3.36E-04
      YS=GOSEP*DHSEP/VISC
      FSS=.184/(2.*DHSEP*YS**0.2)
      DPSF=GOSEP**2/(2.*GC*XRHOS)*XLSEP/(DHSEP)*FSS
      DPSG=G1/GC*XRHOS*XLSEP
      DPSL=XKSEP*GOSEP**2/(2.*GC*XRHOS)
      DPS=DPSF+DPSG+DPSL
C    *  4) REGION D1
      HGPP=HF(P)+HFG(P)
      WST=WO*XROUT
      GO1=(WCORE-WST)/AD1
      X1=-1.41E-05*DH1*12.+3.36E-04
      Y1=GO1*DH1/VISC
      FD1=.184/(2.*DH1*Y1**0.2)
      DP1F=GO1**2/(2.*GC*DENSF)*FL1/DH1*FD1
      DP1G=-G1/GC*DENSF*ZL1
      DP1L=XK1*GO1**2/(2.*GC*DENSF)
      DP1=DP1F+DP1G+DP1L
C    *  5) REGION D2
      WFW=WST
      GOD2=WCORE/AD2
      X2=-1.41E-05*DH2*12.+3.36E-04
      Y2=GOD2*DH2/VISC
      FD2=.184/(2.*DH2*Y2**0.2)
      DPTF=GOD2**2/(2.*GC*DENSF)*FL2/DH2*FD2
      DPTG=-G1/GC*DENSF*ZL2
      DPTL=XK2*GOD2**2/(2.*GC*DENSF)
      DP2=DPTF+DPTG+DPTL
C    *  6) REGION D3
      GO3=WCORE/AD3
      X3=-1.41E-05*DH3*12.+3.36E-04
      Y3=GO3*DH3/VISC
      FD3=.184/(2.*DH3*Y3**0.2)
      DP3F=GO3**2/(2.*GC*DENSF)*FL3/DH3*FD3
      DP3G=-G1/GC*DENSF*ZL3
      DP3L=XK3*GO3**2/(2.*GC*DENSF)
      DP3T=DP3F+DP3G+DP3L
C    *  7) LOWER PLENUM
      GOLP=WCORE/ADLP
      XLP=-1.41E-05*DHLP*12.+3.36E-04
      YLP=GOLP*DHLP/VISC
      FLP=.184/(2.*DHLP*YLP**0.2)
      DPLPF=GOLP**2/(2.*GC*DENSF)*FLLP/DHLP*FLP
      DPLPG=G1/GC*DENSF*ZLLP
      DPLPL=XKLP*GOLP**2/(2.*GC*DENSF)
      DPLP=DPLPF+DPLPG+DPLPL
C    * III) TOTAL EXTERNAL LOOP PRESSURE DROP(EXCLUDING PUMP)
      DPLOOP=DPU+DPR+DPS+DP1+DP2+DP3T+DPLP
C    *  8) REGION D3(PUMP)
      PFW=WCORE*3600./1.E+06/2.
      PA=0.
      PB=0.
      DP3=DPTS+DPLOOP
      IF(IPUMP .NE. 0)DPX=DP3
C
      CALL PUMP(IPUMP,SPUMP,AA,DPX,PFW,DENSI,G1,GC)
      CPUMP=SPUMP*100.
C
      DPLPT=DPLOOP
      IF(IV .EQ. 0)GO TO 79
      SLOOP=FL1/AD1+FL2/AD2+FL3/AD3+FLLP/ADLP
      SFLOOP=(FD1*FL1/DH1+XK1)/AD1**2+(FD2*FL2/DH2+XK2)/AD2**2+
     @  (FD3*FL3/DH3+XK3)/AD3**2+(FLP*FLLP/DHLP+XKLP)/ADLP**2
   79 CONTINUE
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
C
C    * CALCULATE THE PARAMETERS FOR THE DELHI
C
      IF(ICAL .EQ. 3 .OR. ICAL .EQ. 5) GO TO 102
      GO TO 100
  102 CH3 = (PHV*HOD/WO/CPF) / (1.+THV*HOD/DKV)
      CH4 = (ENTHP-HFW) * (XROUT*WO/WO**2)
      CH5 = HOD/(1.+THV*HOD/DKV) * (TEMINV - TEMV)
      CH6 = (1.-XROUT)*ENTHP + XROUT*HFW
      CHH = -CH3*DLENG
      CH7 = (PHV*CH5/WO/CH3) * (EXP(CHH)-1.) + CH6
      CH8 = HOLP*(TIN-TEMV) / (1.+HOLP*THLP/DKV)
C
  100 WRITE(6,15)
      WRP1=RP1-ALHEAT
      WRP2=RP2-RP1
      WRL=RL-RP2
      WRITE(6,17) AP,WRP1,WRP2,RPO,DHUP
      WRITE(6,19) UPALP, UPJIN
      WRITE(6,21)
      WRITE(6,23)WRL,AR, DR, COR, VGJR
      WRITE(6,25) GOR, VRO, ALPRO, CORPR
      WRITE(6,398)
      WRITE(6,397)
      WRITE(6,399)XINER,XLSEP,XKSEP,XASEP,DHSEP
  398 FORMAT(/,5X,'PARAMETERS FOR STEAM SEPARATOR ')
  397 FORMAT(/11X,'INER',9X,'LENGTH',7X,'LOSS COEF.',4X,
     @         'FLOW AREA',5X,'HYDR. DIAM.')
  399 FORMAT(/,8X,4(E12.4,2X),E12.4)
      WRITE(6,27)
      WRITE(6,29) SLOOP, SFLOOP, AA
      IF(ICAL .EQ. 3 .OR. ICAL .EQ. 5) GO TO 200
      GO TO 101  .
  200   WRITE(6,31)
        WRITE(6,33) HFW, ADC, DLENG, TEMV, TEMINV, PHV, HOD
        WRITE(6,35) THV, DKV, CPV, DENV
        WRITE(6,37) WO, CH6, CH7
        WRITE(6,39)
        WRITE(6,33) PLM, AHLP, HOLP, THLP, CH5
      WRITE(6,62)
   62 FORMAT(//,'DOWNCOMER GEOMETRY')
      WRITE(6,64)
   64 FORMAT(/,18X,'LENGTH',9X,'  FLOW AREA',7X,'HYDR. DIAM.',
     @         7X,'LOSS COEF.')
      WRITE(6,65)ZL1,AD1,DH1,XK1
   65 FORMAT(/,'DOWNCOMER 1     ',3(E12.4,5X),E12.4)
      WRITE(6,66)ZL2,AD2,DH2,XK2
   66 FORMAT(/,'DOWNCOMER 2     ',3(E12.4,5X),E12.4)
      WRITE(6,67)ZL3,AD3,DH3,XK3
   67 FORMAT(/,'DOWNCOMER 3     ',3(E12.4,5X),E12.4)
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      WRITE(6,188)
  188 FORMAT(//,'PRESSURE DROPS (PSI) IN RECIRCULATION LOOP')
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      WRITE(6,190)
  190 FORMAT(/,19X,'FRICTION',9X,'GRAVITY',9X,'LOCAL LOSS',9X,
     @       'TOTAL')
      WRITE(6,84)DPUF,DPUG,DPUL,DPU
   84 FORMAT(/,'UPPER PLENUM   ',2X,3(E12.4,5X),E12.4)
      WRITE(6,85)DPRF,DPRG,DPRL,DPR
   85 FORMAT(/,'RISER          ',2X,3(E12.4,5X),E12.4)
      WRITE(6,185)DPSF,DPSG,DPSL,DPS
  185 FORMAT(/,'STEAM SEPARATOR',2X,3(E12.4,5X),E12.4)
      WRITE(6,80)DP1F,DP1G,DP1L,DP1
   80 FORMAT(/,'DOWNCOMER 1    ',2X,3(E12.4,5X),E12.4)
      WRITE(6,81)DPTF,DPTG,DPTL,DP2
   81 FORMAT(/,'DOWNCOMER 2    ',2X,3(E12.4,5X),E12.4)
      WRITE(6,86)DP3F,DP3G,DP3L,DP3T
   86 FORMAT(/,'DOWNCOMER 3    ',2X,3(E12.4,5X),E12.4)
      WRITE(6,186)
  186 FORMAT('EXCLUDING PUMP')
      DPY=-DPX
      WRITE(6,983)CPUMP,DPY
  983 FORMAT(/,'PUMP           ',2X,'(PUMP SPEED ',E12.4,' % RATED)',
     @       19X,E12.4)
      WRITE(6,83)DPLPF,DPLPG,DPLPL,DPLP
   83 FORMAT(/,'LOWER PLENUM   ',2X,3(E12.4,5X),E12.4)
      TLDP=DPU+DPR+DPS+DP1+DP2+DP3T+DPY+DPLP
      WRITE(6,986)TLDP
  986 FORMAT(/,'TOTAL EXTERNAL LOOP PRESSURE DROP',35X,E12.4)
   96 FORMAT(//3X,'TOTAL PRESSURE DROP(PSI) IN HEATED CHANNEL IS
     @ ',2X,E10.4)
   97 FORMAT(3X,'TOTAL DP IN EXTERNAL LOOP EXCLUDING  PUMP IS  ',
     @  E10.4)
   98 FORMAT(3X,'PRESSURE DROP IN  PUMP (PSI) IS',
     @       2X,E10.4)
  982 FORMAT(3X,'PUMP HEAD REQUIRED(PSI) IS  ',E10.4)
   99 FORMAT(3X,'PUMP SPEED IS  ',E10.4,1X,'%  RATED SPEED')
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
  101 RETURN
      END
C
      SUBROUTINE PUMP(IPUMP,SPUMP,AA,DP3,PFW,DENSI,G1,GC)
      DATA A12,A11,A10,B12,B11,B10/0.,-.99,-0.026,162.13,2.724,
     @     0.0 /
      DATA A22,A21,A20,B22,B21,B20/0.,0.,-.62,0.,103.03,-1.82/
      F(C2,C1,C0)=C2*SPUMP**2+C1*SPUMP+C0
      IF(IPUMP .NE. 0)GO TO 50
      IF(SPUMP .GE. .60)GO TO 252
      PA=F(A12,A11,A10)
      IF(SPUMP .LE. 1.E-5)PA=0.0
      PB=F(B12,B11,B10)
      GO TO 54
  252 PA=F(A22,A21,A20)
      PB=F(B22,B21,B20)
   54 CONTINUE
      DP3=(PA*PFW+PB)*DENSI*G1/GC
      GO TO 56
   50 CONTINUE
      IF(DP3 .GE. 0. .AND. DP3 .LE. 1.E-5)GO TO 55
      IF(DP3 .LE. 0.)GO TO 55
      ALP=DP3/(DENSI*G1/GC)
      SPUMP=.60
      PA60=F(A12,A11,A10)
      PB60=F(B12,B11,B10)
      CDP3=(PA60*PFW+PB60)*DENSI*G1/GC
      IF(DP3 .GE. CDP3)GO TO 60
      E2=A12
      E1=A11
      E0=A10
      F2=B12
      F1=B11
      F0=B10
      GO TO 65
   60 E2=A22
      E1=A21
      E0=A20
      F2=B22
      F1=B21
      F0=B20
   65 CONTINUE
      A=E2*PFW+F2
      B=E1*PFW+F1
      C=E0*PFW+F0-ALP
      SPUMP=(-B+SQRT(B*B-4.*A*C))/(2.*A)
      GO TO 656
   55 SPUMP=0.00
  656 CONTINUE
      PA=F(E2,E1,E0)
      PB=F(F2,F1,F0)
   56 CONTINUE
      AA=2./3.*PA*(DENSI*G1/GC)*3600./1.E+06
      RETURN
      END
C
C
C
C
C*******************************************************************
      SUBROUTINE CON2DP(S, INODE)
C*******************************************************************
C
C        . . . CALCULATE THE CONSTANTS FOR TWO-PHASE PRESSURE DROP
C                        PERTURBATION CALCULATION
C
      REAL K1
      COMPLEX S,TG,STC1,STC2,TB1,TB2,CSTB1,CSTB2,TF,TR1,TR2,
     1        XX1, XX2
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPFPPPPPPPPPPPPPPPPPPPPPP
      COMPLEX A1P(30),B1P(30),STC51,STC52,STC53,STC54,STC55
     1       ,STC56,M4,STC3,STC4,STC5,STC6,PP,TALP2,TALP3
     2       ,TALP4,TLP4,CLTX,RR4,DGAMP,STC2P
     3       ,PPS,C1B,C2B,C3B,CSBX3,ZP,C4B,PA2,RP,R2,R3
      COMMON /CMP2/TG(11,30),TB1(4,30),TB2(4,30),TF(19,30),
     1       TR1(12,30),TR2(12,30)
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      COMMON/CONST1/ C1(5),C2(5),C3(5),C4,C5(5),C8(5,30),
     1       C9(5,30),C18(5), C21(5), C22(5),C25(5),
     2       C26(5), T6, V7(5), DD1, CK1, CMP
      COMMON/OPTION/ IOSUB, IOHW, IO2Q, IPILO, ISLIP, IRW
      COMMON/CONST2/ P,VCH,VIN(5),AXS(5),DH(5),DHIN(5),
     1       PH(5),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2       DENSF,VFG1,RHOG,G0(5),G02(5),H0(5),GC,G1,KLOSS(30),
     3       FRICMO(5),VGJH(5,30),COH(5,30),CZERO,VGJ,DPTS,
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     4        CO2RF(5),HFGI,ZSP(30),NUMBSP(5,30),ALHEAT,CXF(5),
     5        AVEQ,CHOMO1,CHOMO2,XKIN(5),XKEXIT(5)
      COMMON/CONSS1/ QDIS(5,30),QD(5,30),DZ(5,30),Z(5,30),
     1        K1(5,30), CKIN(5,30), ZETA(5,30), DOIN(5,30),
     2        DOOUT(5,30), ALPIN(5,30), BEE(5,30),CPI1(5,30),
     3        COR2PH(5,30), ZETSP(5,30), WIN
      COMMON /DIM1/ DELX, DELZ, CHLAMB(5), ALFNOD(5,30),
     1              BBLAMB(5)
      COMMON/CONSS2/ NTOT(5),NBB(5),NBB1(5),NSP,N1PSP(5),
     1               K2PSP(5), NDP(5), NDP1(5), ISUB(5)
      COMMON /DPCON3/ ST2(30)
      COMMON /DPCON2/ STC1(30), STC(5,30), CSTB1(30), CSTB2(30),
     1                STC2(30)
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMMON/COREP/ STC3(30),STC4(30),STC5(30),STC6(30),PP(30),
     1              TALP2(5,30,30),TALP4(5,30),TLP4,PJ
      COMMON/DELTAP/DGAMP,DRHOG,DHF,DHG,DCZERO,DVGJ,DCOR,DVGJR
      COMMON/RISERP/CLTX,RR4,CRP5,CRP8,RO13,RO23,CL12,UPJ3,ALPRO,
     1              GOR,RHOR,VRO,CRCON,UPALP
      COMMON/PCON2P/PPS(30)
      COMMON/PSP/CSBX3(5,30),ALOUT(5,30)
      COMMON/PWD/ZP(30)
      COMMON/KEY/IKEY
      COMMON/PGAM/IGAM,IDRF
      COMMON/HLP/PHL(5,30),EPSUB(5,30)
      COMMON/YV/YV1IN,YV2IN,YV3IN,YV4IN,YV1OT,YV2OT,YV3OT,YV4OT
      COMMON/CFSUB/CF(5,30),CG(5,30)
      COMMON/SUBPP/PVGH(5,30)
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      DRF=DRFDP(P)
      IF(IDRF .EQ. 0)DRF=0.
      DRGFP=DRGDP(P)-RHOG/DENSF*DRF
      DDR=DRGDP(P)-DRF
C
      NP1 = NTOT(INODE)
      NST = NDP1(INODE)
      DO 100 I=NST,NP1
      CZERO=COH(INODE,I)
      VGJ=VGJH(INODE,I)
      C15=DENSF/(C4*CZERO)
      ST1 = DENSF - C4*ALPIN(INODE,I)*COH(INODE,I)
      ST2(I) = ST1*CKIN(INODE,I)/C4
      STC2(I) = ST2(I)/(S-COH(INODE,I)*K1(INODE,I))/CKIN(INODE,I)**2
      STC1(I) = S / (COH(INODE,I)*K1(INODE,I))
      TG(1,I) = ST1 / (1.-1./STC1(I))
      TG(2,I) = -ST1 /(STC1(I)-1.)
      TG(3,I) = ST1*CKIN(INODE,I)/COH(INODE,I)/K1(INODE,I)
      TG(4,I) = - TG(3,I) - C4*STC2(I)*CKIN(INODE,I)**2
      TG(5,I) = ST1/(S-COH(INODE,I)*K1(INODE,I)) * CKIN(INODE,I)
      TG(6,I) = -C4*CKIN(INODE,I)
C
      XX1 = STC1(I) * ALOG(ZETA(INODE,I))
      CSTB1(I) = CEXP(XX1)
      XX2 = (1. + STC1(I)) * ALOG(ZETA(INODE,I))
      CSTB2(I) = CEXP(XX2)
      TB1(1,I) = 2.*(GO(INODE)/DOIN(INODE,I))*(TG(1,I) + TG(2,I))
      TB2(1,I) = 2.*(GO(INODE)/DOOUT(INODE,I))*(TG(1,I)/ZETA(INODE,I)
     1        + TG(2,I)/CSTB1(I)) - (GO(INODE)/DOOUT(INODE,I))**2 *
     2        C4*COH(INODE,I)*K1(INODE,I)*STC2(I)*(1./ZETA(INODE,I)**2
     3        - 1./CSTB2(I))
      TB1(2,I) = 2.*(GO(INODE)/DOIN(INODE,I))*(TG(3,I) + TG(4,I) +
     1            TG(5,I))
      TB2(2,I) = 2.*(GO(INODE)/DOOUT(INODE,I))*(TG(3,I) +
     1                        TG(4,I)/ZETA(INODE,I) + TG(5,I)/CSTB1(I))
     2          + (GO(INODE)/DOOUT(INODE,I))**2*C4*STC2(I)*
     3              CKIN(INODE,I)*(1./ZETA(INODE,I)**2 - 1./CSTB2(I))
      TB1(3,I) = 2.*(GO(INODE)/DOIN(INODE,I))*TG(6,I) +
     1            (GO(INODE)/DOIN(INODE,I))**2*C4
      TB2(3,I) = 2.*(GO(INODE)/DOOUT(INODE,I))*TG(6,I)/CSTB1(I) +
     1            (GO(INODE)/DOOUT(INODE,I))**2*C4/CSTB2(I)
C
      C14 = CPI1(INODE,I) * (VFG1*DENSF)
      C11 = VGJH(INODE,I)/(COH(INODE,I)*VFG1*GO2(INODE))
      C12 = COH(INODE,I)*VFG1*GO2(INODE)
      TF(1,I) = (CPI1(INODE,I)*DENSF/GO(INODE)) * (1. - CKIN(INODE,I)
     1                  *TG(1,I)/COH(INODE,I)/GO(INODE))
      TF(2,I) = C14*C11*TG(1,I)
      TF(3,I) = C14*C11*TG(2,I)
      TF(4,I) =-C14*(CKIN(INODE,I)/C12)*TG(2,I)
      TF(5,I) = (CPI1(INODE,I)*DENSF/(GO(INODE)*COH(INODE,I))) *
     1     ( -CKIN(INODE,I)/K1(INODE,I) + (VGJH(INODE,I)/GO(INODE))*
     1     TG(3,I) - (CKIN(INODE,I)/GO(INODE))*TG(4,I) )
      TF(6,I) = CPI1(INODE,I)*VGJH(INODE,I)*DENSF/(GO2(INODE)*
     1     COH(INODE,I)) * TG(4,I)
      TF(7,I) = CPI1(INODE,I)*DENSF/(COH(INODE,I)*GO(INODE)) * (
     1      CKIN(INODE,I)/K1(INODE,I)-CKIN(INODE,I)/GO(INODE)*TG(3,I) )
      TF(8,I) = C14*C11*TG(5,I)
      TF(9,I) =-C14*(CKIN(INODE,I)/C12)*TG(5,I)
      TF(10,I) = C14*C11*TG(6,I)
      TF(11,I) =-C14*(CKIN(INODE,I)/C12)*TG(6,I)
C
      VGJIN  = ((COH(INODE,I)-1.)*CKIN(INODE,I) + VGJH(INODE,I))/
     1           COH(INODE,I)
      VGJOUT = ((COH(INODE,I)-1.)*CKIN(INODE,I)*ZETA(INODE,I) +
     1             VGJH(INODE,I))/COH(INODE,I)
      V1IN  = (DENSF*RHOG*VGJIN**2/(DOIN(INODE,I)**2 - RHOG*
     1         DOIN(INODE,I))**2)  *  (2.*DENSF*DOIN(INODE,I) -
     2           DOIN(INODE,I)**2 - DENSF*RHOG)
      V1OUT  = (DENSF*RHOG*VGJOUT**2/(DOOUT(INODE,I)**2 -
     1    RHOG*DOOUT(INODE,I))**2)  *  (2.*DENSF*DOOUT(INODE,I) -
     2           DOOUT(INODE,I)**2 - DENSF*RHOG)
      V2IN  = ((DENSF - DOIN(INODE,I))/(DOIN(INODE,I) - RHOG))
     1         * (DENSF*RHOG/DOIN(INODE,I)) * VGJIN
      V2OUT = ((DENSF - DOOUT(INODE,I))/(DOOUT(INODE,I) - RHOG))
     1         * (DENSF*RHOG/DOOUT(INODE,I)) * VGJOUT
      TR1(1,I) = 2.*V2IN*(COH(INODE,I) - 1.)
      TR2(1,I) = 2.*V2OUT*(COH(INODE,I) - 1.)
      TR1(2,I) = - V1IN*C4*STC2(I)*COH(INODE,I)*K1(INODE,I)
      TR2(2,I) = - V1OUT*C4*STC2(I)*COH(INODE,I)*K1(INODE,I)
      TR1(3,I) = -TR1(1,I)*CKIN(INODE,I)/COH(INODE,I)/K1(INODE,I)
      TR2(3,I) = -TR2(1,I)*CKIN(INODE,I)/COH(INODE,I)/K1(INODE,I)
      TR1(4,I) = V1IN*C4*STC2(I)*CKIN(INODE,I)
      TR2(4,I) = V1OUT*C4*STC2(I)*CKIN(INODE,I)
      TR1(5,I) = V1IN*C4
      TR2(5,I) = V1OUT*C4
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C ADDITIONAL EQUATION TO CALCULATE SYSTEM PRESSURE PERTURBAITON
      XCIN=CKIN(INODE,I)/(CZERO*K1(INODE,I))
      P1K=CKIN(INODE,I)*CZERO*(C15-ALPIN(INODE,I))
      FF=1.
      HLG1=HFG1
      A1P(I)=CKIN(INODE,I)/(CZERO*K1(INODE,I))*
     @       (VFG1*S/(HFG1*PJ)*FF
     1  -(DENSF*S*VFG1*FF-K1(INODE,I))/HFG1*DHF-K1(INODE,I)/HFG1
     2       *DHG+K1(INODE,I)/VFG1*DVFGDP(P)
     3       +S/(CZERO*RHOG)*(DENSF/HFG1*DHF*FF
     4  -RHOG/HFG1*DHG-DENSF/C4*DRHOG)+1./(PJ*HFG1)*(1.-FF))
      IF(IOSUB .NE. 0 .AND. I .LT. NBB1(INODE))GO TO 105
      A1P(I)=A1P(I)+ZP(I)*CKIN(INODE,I)/(QO(INODE,I)*CZERO)
  105 A1P(I)=A1P(I)-S/DENSF*DRF*(1.-DENSF/CZERO/C4)*XCIN
      B1P(I)=CKIN(INODE,I)*S/(CZERO*K1(INODE,I))*(ALPIN(INODE,I)
     1       -DENSF/(CZERO*C4))*(VFG1*DENSF/HFG1*DHF*FF
     2 -VFG1*RHOG/HFG1*DHG-1./RHOG*DRHOG+VFG1/(PJ*HFG1)*(1.-FF))
      B1P(I)=B1P(I)-S/DENSF*DRF*P1K/(CZERO*CKIN(INODE,I))*XCIN
      PA2=1.+S/(CZERO*K1(INODE,I))
      P1CK=(DENSF/C4-CZERO*ALPIN(INODE,I))*CKIN(INODE,I)
      C1B=-C15/RHOG
      C2B=-C1B*S/(CZERO*K1(INODE,I))/HFG1*
     @    (DENSF*DHF1(P)*FF-RHOG*DHG1(P)+1./PJ*(1.-FF))+
     @    1./(RHOG*CZERO*K1(INODE,I)*HFG1)*
     @    (-K1(INODE,I)/VFG1*DHFGDP(P)+
     @    S*(1./PJ*FF-DENSF*DHF1(P)*FF))
      IF(IOSUB .NE. 0 .AND. I .LT. NBB1(INODE))GO TO 110
      C2B=C2B+PH(INODE)*ZP(I)/(HFG1*AXS(INODE))
     @    /(CZERO*K1(INODE,I)*RHOG)
  110 C3B=S/HFG1*(DENSF*DHF1(P)*FF-RHOG*DHG1(P)+1./PJ*(1.-FF))
      C4B=0.
      NSOS=NBB1(INODE)
      STC3(I)=(C1B*DRHOG-C15*DRHOG/RHOG*(PA2-1.)-C15/CZERO*
     @          DCZERO-DENSF*A1P(I)/(C4*CKIN(INODE,I))+C2B)/PA2
      STC4(I)=(P1CK/(CZERO**2*K1(INODE,I)*RHOG*CKIN(INODE,I))*
     @          (S*DRHOG-C3B)-DENSF*CZERO/C4*
     @          B1P(I)/CKIN(INODE,I)+C4B)/(PA2-1.)
      STC5(I)=P1CK/CKIN(INODE,I)**2*((VGJ*DCZERO-CZERO*DVGJ)/
     @          CZERO**2+A1P(I)+B1P(I))/(PA2-2.)
      STC6(I)=-P1CK/CKIN(INODE,I)**2/(PA2-2.)*B1P(I)
      TG(7,I)=ST1*A1P(I)+(CKIN(INODE,I)*ST1+VGJ*DENSF)
     1         /(CZERO**2)*DCZERO-CKIN(INODE,I)/(CZERO*C4)
     2         *ST1*DRHOG-C4*CKIN(INODE,I)*STC4(I)
     3         -DENSF/CZERO*DVGJ
      TG(7,I)=TG(7,I)-VGJ/CZERO*DRF
      TG(8,I)=CKIN(INODE,I)*DENSF/(CZERO*C4)*DRHOG
     1         -CKIN(INODE,I)*DENSF/(CZERO**2)*DCZERO
     2         -C4*CKIN(INODE,I)*STC3(I)
      TG(8,I)=TG(8,I)+CKIN(INODE,I)/CZERO*DRF
      TG(9,I)=ST1*(1/CZERO*DVGJ-VGJ/CZERO**2*DCZERO-A1P(I))
     1          -C4*CKIN(INODE,I)*STC5(I)
      TG(9,I)=TG(9,I)+C4*CKIN(INODE,I)*STC6(I)/(PA2-2.)
      TG(10,I)=C4*CKIN(INODE,I)*(STC3(I)+STC4(I)+STC5(I))
      TG(10,I)=TG(10,I)-C4*CKIN(INODE,I)*STC6(I)/(PA2-2.)
      TG(11,I)=ST1*B1P(I)-C4*CKIN(INODE,I)*STC6(I)
      TB1(4,I)=2*GO(INODE)/DOIN(INODE,I)*(TG(7,I)
     1          +TG(8,I)+TG(9,I)+TG(10,I))
     2          -GO2(INODE)/DOIN(INODE,I)**2*(DRF
     3          +ALPIN(INODE,I)*DDR)
      TB2(4,I)=2*GO(INODE)/DOOUT(INODE,I)*(TG(7,I)
     1          +TG(8,I)*ZETA(INODE,I)+TG(9,I)/ZETA(INODE,I)
     2           +TG(10,I)/CSTB1(I)+TG(11,I)/ZETA(INODE,I)
     3          *ALOG(ZETA(INODE,I)))
     4    -(GO(INODE)/DOOUT(INODE,I))**2*(ALOUT(INODE,I)*DDR+DRF)
     6        +GO2(INODE)*C4/DOOUT(INODE,I)**2*(STC3(I)
     7        *(1-1/CSTB2(I))+STC4(I)*(1/ZETA(INODE,I)-1/CSTB2(I))
     8        +STC5(I)*(1/ZETA(INODE,I)**2-1/CSTB2(I))
     9       +STC6(I)*(1./ZETA(INODE,I)**2*(ALOG(ZETA(INODE,I))
     @       -1./(PA2-2.))+1./CSTB2(I)/(PA2-2.)))
      TF(12,I)=CPI1(INODE,I)*DENSF/GO2(INODE)*(-GO(INODE)*A1P(I)
     1          -CKIN(INODE,I)/CZERO*TG(9,I)+VGJ/CZERO*TG(7,I))
      TF(13,I)=CPI1(INODE,I)*DENSF*VGJ/(GO2(INODE)*CZERO)
     1          *TG(9,I)
      TF(14,I)=CPI1(INODE,I)*DENSF/GO2(INODE)*(GO(INODE)*A1P(I)
     1          -CKIN(INODE,I)/CZERO*TG(7,I)+VGJ/CZERO*TG(8,I))
      TF(15,I)=-CPI1(INODE,I)*DENSF*CKIN(INODE,I)/(GO2(INODE)*CZERO)
     1          *TG(8,I)
      TF(16,I)=CPI1(INODE,I)*DENSF*VGJ/(GO2(INODE)*CZERO)*TG(10,I)
      TF(17,I)=-CPI1(INODE,I)*DENSF*CKIN(INODE,I)/(GO2(INODE)
     1          *CZERO)*TG(10,I)
      TF(18,I)=CPI1(INODE,I)*DENSF/GO2(INODE)*(GO(INODE)*B1P(I)
     1         -CKIN(INODE,I)/CZERO*TG(11,I))
      TF(19,I)=CPI1(INODE,I)*DENSF*VGJ/(GO2(INODE)*CZERO)*TG(11,I)
      V3IN=2*V2IN*(DVGJ-VGJ/CZERO*DCZERO)
     1    +(VGJIN**2*DENSF*(DENSF-DOIN(INODE,I))/
     2    (DOIN(INODE,I)-RHOG)**2)*DRHOG
      V3IN=V3IN+VGJIN**2*RHOG*(2.*DENSF-DOIN(INODE,I))/DOIN(INODE,I)
     @    /(DOIN(INODE,I)-RHOG)*DRF
      V3OUT=2*V2OUT*(DVGJ-VGJ/CZERO*DCZERO)
     1    +(VGJOUT**2*DENSF*(DENSF-DOOUT(INODE,I))/
     2    (DOOUT(INODE,I)-RHOG)**2)*DRHOG
      V3OUT=V3OUT+VGJOUT**2*RHOG*(2.*DENSF-DOOUT(INODE,I))/
     @      DOOUT(INODE,I)/(DOOUT(INODE,I)-RHOG)*DRF
      V4IN=2*V2IN*CKIN(INODE,I)/CZERO*DCZERO
      V4OUT=2*V2OUT*CKIN(INODE,I)/CZERO*DCZERO
      PP(I)=A1P(I)*CZERO*K1(INODE,I)/CKIN(INODE,I)
     1      *DZ(INODE,I)+B1P(I)*ALOG(CZERO*K1(INODE,I)
     2      /CKIN(INODE,I)*DZ(INODE,I)+1)
      ZZZ=ZETA(INODE,I)
      PPS(I)=XCIN/DZ(INODE,I)*(A1P(I)*(ZZZ-1.)**2/2.+B1P(I)*
     @ (ZZZ*(ALOG(ZZZ)-1.)+1.))
      TR1(6,I)=V1IN*C4*STC3(I)
     @         -2*V2IN*(CZERO-1)*A1P(I)
     1         +V3IN-V1IN*DENSF/(CZERO*C4)*DRHOG
      TR1(6,I)=TR1(6,I)-V1IN*DRF
      TR2(6,I)=V1OUT*C4*STC3(I)
     @         -2*V2OUT*(CZERO-1)*A1P(I)
     1         +V3OUT-V1OUT*DENSF/(CZERO*C4)*DRHOG
      TR2(6,I)=TR2(6,I)-V1OUT*DRF
      TR1(7,I)=2*V2IN*(CZERO-1)*A1P(I)+V4IN
      TR2(7,I)=2*V2OUT*(CZERO-1)*A1P(I)+V4OUT
      TR1(8,I)=V1IN*C4*STC4(I)+V1IN/(CZERO*C4)*ST1*DRHOG
      TR2(8,I)=V1OUT*C4*STC4(I)+V1OUT/(CZERO*C4)*ST1*DRHOG
      TR1(9,I)=V1IN*C4*(STC5(I)-STC6(I)/(PA2-2.))
      TR2(9,I)=V1OUT*C4*(STC5(I)-STC6(I)/(PA2-2.))
      TR1(10,I)=-V1IN*C4*(STC3(I)+STC4(I)+STC5(I)-STC6(I)/(PA2-2.))
      TR2(10,I)=-V1OUT*C4*(STC3(I)+STC4(I)+STC5(I)-
     @            STC6(I)/(PA2-2.))
      TR1(11,I)=2*V2IN*(CZERO-1)*B1P(I)
      TR2(11,I)=2*V2OUT*(CZERO-1)*B1P(I)
      TR1(12,I)=V1IN*C4*STC6(I)
      TR2(12,I)=V1OUT*C4*STC6(I)
C
```

```
  100 CONTINUE
      RETURN
      END
C
C
C
C
C*****************************************************************
      SUBROUTINE WALLDY(S, INODE)
C*****************************************************************
C
C       ..... CALCULATE HEATED WALL DYNAMICS
C             1) I=1  ; LUMPED PARAMETER MODEL
C             2) I=2  ; TWO-PARALLEL PLATE
C             3) I=3  ; CYLINDRICAL TUBE WITH INNER HEATING
C             4) I=4  ; HOMOGENIZED FUEL ASSEMBLY
C
C
      REAL KF,KLOSS,K1
      COMPLEX Z1,Z2,Z3, S, EP, WC,WC1,WC2,WDEN, CCOTH, EP1,EP2,EPF,
     1        EPC, BSI0,BSI1,BSK0,BSK1,CSBX3,ZP,Y1,Y2,SA,SB
      COMMON/OPTION/ IOSUB, IOPT, KOPT, IPILO, ISLIP, IRW
      COMMON /CONWD1/ CPH,TKH,DENSH,CPC,TKC,DENSC,CRS,CRI,CRO,
     1               GAPC, V22(5,30), THICKH
      COMMON/CONST2/ P,VCH,VIN(5),AXS(5),DH(5),DHIN(5),
     1       PH(5),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2       DENSF,VFG1,RHOG,G0(5),G02(5),H0(5),GC,G1,KLOSS(30),
     3       FRICHO(5),VGJH(5,30),COH(5,30),CZERO,VGJ,DPTS,
     4       G02RF(5),HFG1,ZSP(30),NUMBSP(5,30),ALHEAT,CXF(5),
     5       AVEQ,CHOMO1,CHOMO2,XKIN(5),XKEXIT(5)
      COMMON /WD2/Z1, Z2, Z3(30)
      COMMON/CONSS1/QDIS(5,30),Q0(5,30),DZ(5,30),Z(5,30)
     @        ,K1(5,30),CKIN(5,30),ZETA(5,30),D0IN(5,30)
     @        ,D0OUT(5,30),ALPIN(5,30),BEE(5,30),CPI1(5,30)
     @        ,COR2PH(5,30),ZETSP(5,30),WIN
      COMMON/CONSS2/ NTOT(5),NBB(5),NBB1(5),NSP,N1PSP(5),
     1              K2PSP(5), NDP(5), NDP1(5), ISUB(5)
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMMON/PSP/CSBX3(5,30), ALOUT(5,30)
      COMMON/PWD/ZP(30)
      COMMON/WKM/XWK,XWM
      COMMON/DPLER1/Y1,Y2
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      W = AIMAG(S)
      N1 = NDP1(INODE)
      N2 = NTOT(INODE)
      IF(IOPT .EQ. 2) GO TO 1
      IF(IOPT .EQ. 3) GO TO 2
      IF(IOPT .EQ. 4) GO TO 3
C
C    * LUMPED PARAMETER MODEL
C
      Z1 = -PH(INODE)/(DENSH*CXF(INODE)*CPH*S)
      Z2 = 1./(DENSH*CPH*S)
      GO TO 100
C
C    * TWO-PARALLEL PLATE
C
    1 EP = S*DENSH*CPH/TKH
```

```
      EP = CSQRT(EP)
      WC = EP*THICKH
      Y1=-1./(EP*EP*TKH*THICKH)
      Y2=1./(DENSH*CPH*S)
      Z1 = -CCOTH(WC)/(EP*TKH)
      Z2 = 1. / (DENSH*CPH*S)
      GO TO 100
C
C    * CYLINDRICAL TUBE WITH INNER HEATING
C
    2 EP1 = S*DENSH*CPH/TKH
      SU =  W*DENSH*CPH/TKH
      EP = CSQRT(EP1)
      RI = SU*CRI
      RO = SU*CRO
      WC1 = BSK1(RO)*BSI0(RO) + BSI1(RO)*BSK0(RO)
      WC2 = BSI1(RI)*BSK1(RO) - BSK1(RI)*BSI1(RO)
      Y1=-1./(EP*EP*TKH)*2.*CRI/(CRO*CRO-CRI*CRI)
      Y2=1./(DENSH*CPH*S)
      Z1 =  (WC1/WC2) / (EP*TKH)
      Z2 = 1./(DENSH*CPH*S)
      GO TO 100
C
C    * THE HOMOGENIZED CORE FUEL ASSEMBLY
C
    3 EP1 = S*DENSH*CPH/TKH
      EP2 = S*DENSC*CPC/TKC
      EPF = CSQRT(EP1)
      EPC = CSQRT(EP2)
      SUF1 = W*DENSH*CPH/TKH
      SUC1 = W*DENSC*CPC/TKC
      SUF2 = SQRT(SUF1)
      SUC2 = SQRT(SUC1)
      RS = SUF2*CRS
      RI = SUC2*CRI
      RO = SUC2*CRO
      RSI = CRI/CRS
      WC = EPC*TKC*(BSI0(RS)/(TKH*EPF*BSI1(RS))*RSI + 1./GAPC)
      WC1 = BSI0(RI) - WC*BSI1(RI)
      WC2 = BSK0(RI) + WC*BSK1(RI)
      WDEN = WC2*BSI1(RO) + WC1*BSK1(RO)
C
      SA=(WC1*BSK1(RI)+WC2*BSI1(RI))/WDEN
      SB=EPC*TKC/WDEN*(BSI1(RI)*BSK1(RO)-BSI1(RO)*BSK1(RI))
      Y1=-1./(EPF*EPF*TKH)*2.*CRI/(CRO*CRS)
      Y2=1./(DENSH*CPH*S)*(1.+2.*SB*CRI/(CRO*CRS*EPF*EPF*TKH))
      Z1 = (1./EPC/TKC) * (-WC2*BSI0(RO) + WC1*BSK0(RO)) / WDEN
      Z2 = (1./(DENSH*CPH*S))*(BSI0(RO)*BSK1(RO)+BSK0(RO)*BSI1(RO))
     1      / WDEN
C
  100 IF(KOPT .EQ. 0) GO TO 4
      PE=GO(INODE)*DH(INODE)*CPF/KF
      DO 10 I=N1,N2
      Z3(I) = V22(INODE,I)*Z2/(1. - V22(INODE,I)*Z1)
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      C1=XWK*QO(INODE,I)-V22(INODE,I)*DTSDP(P)
      ZP(I)=C1/(1.-V22(INODE,I)*Z1)
      CSBX3(INODE,I)=DHF1(P)
      IF(PE .GT. 7.0E+04)CSBX3(INODE,I)=DHF1(P)-154.*QO(INODE,I)*
     @                    VIN(INODE)/GO2(INODE)*DRFDP(P)
```

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C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      TSDP=DTSDP(P)
   10 CONTINUE
      GO TO 101
C
    4 DO 11 I=N1,N2
      Z3(I) = CMPLX(0.,0.)
   11 CONTINUE
C
  101 RETURN
      END
C
C
C
C
C**********************************************************************
      SUBROUTINE DELBB(S, XLAMB, INODE, X2)
C**********************************************************************
C
C         . . . CALCULATE THE BOILING BOUNDARY PERTURBATION
C
      REAL K1,KLOSS,KF
      COMPLEX PHI,THETA,BETA, HS, HSUM1,HSUM2, Z1,Z2,Z3, TH1,TH2,TH3
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMPLEX PSI,TH4,PM4,STC3,STC4,STC5,STC6,PP,TALP2,TALP3
     1        ,TALP4,TLP4,SM,S1,S3,S4,SH1,SH3,SH4,S2,SH2
      COMPLEX H2KP,XISUM,XI1,XI2,XI3,XI4,XIL,U1,U2,U2S,U3,U4,
     @        Y1,Y2,XIK,ZP
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMPLEX M1, M2, M3, S
      NAMELIST/TH/TH1,TH2,TH3
      NAMELIST/XM/M1,M2,M3
      NAMELIST/THM/TH4,PM4
      NAMELIST/SBHM/SH1,SH3,SH4,CONBB
      DIMENSION SL(30)
      COMMON/OPTION/ IOSUB, IOPT, IO2Q, IPILO, ISLIP, IRW
      COMMON /CPBOIL/ M1, M2, M3, TH1,TH2,TH3, HS(30),PM4,TH4
      COMMON /PBOIL/ CONBB
      COMMON/CONST1/ C1(5),C2(5),C3(5),C4,C5(5),C8(5,30),
     1       C9(5,30),C18(5), C21(5), C22(5),C25(5),
     2       C26(5), T6, V7(5), DD1, CKI, CMP
      COMMON/CONST2/ P,VCH,VIN(5),AXS(5),DH(5),DHIN(5),
     1       PH(5),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2       DENSF,VFG1,RHOG,G0(5),G02(5),H0(5),GC,G1,KLOSS(30),
     3       FRICMO(5),VGJH(5,30),COH(5,30),CZERO,VGJ,DPTS,
     4       G02RF(5),HFG1,ZSP(30),NUMBSP(5,30),ALHEAT,CXF(5),
     5       AVEQ,CHOMO1,CHOMO2,XKIN(5),XKEXIT(5)
      COMMON/CONSS1/ QDIS(5,30),Q0(5,30),DZ(5,30),Z(5,30),
     1       K1(5,30), CKIN(5,30), ZETA(5,30), DOIN(5,30),
     2       DOOUT(5,30),ALPIN(5,30), BEE(5,30),CPI1(5,30),
     3       COR2PH(5,30), ZETSP(5,30), WIN
      COMMON /DIM1/ DELX, DELZ, CHLAMB(5), ALFNOD(5,30),
     1               BBLAMB(5)
      COMMON/CONSS2/ NTOT(5),NBB(5),NBB1(5),NSP,N1PSP(5),
     1              K2PSP(5), NDP(5), NDP1(5), ISUB(5)
      COMMON /WD2/Z1, Z2, Z3(30)
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMMON/COREP/ STC3(30),STC4(30),STC5(30),STC6(30),PP(30),
     1               TALP2(5,30,30),TALP4(5,30),TLP4,PJ
```

```
      COMMON/PGAM/IGAM,IDRF
      COMMON/HLDY/SH1,SH2,SH3,SH4
      COMMON/HLDZ/H2KP(30)
      COMMON/PWD/ZP(30)
      COMMON/DPLER1/Y1,Y2
      COMMON/DPLER2/U1(5,30),U2(5,30),U2S(5,30),U3(5,30),U4(5,30),
     @              XIL(5,30)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C PPPPPPPPPPPP?PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPrPPPPPPPPPPPPPPP
C
      DRF=DRFDP(P)
      IF(IDRF .EQ. 0)DRF=0.
C
      IF(IOPT .EQ. 0) GO TO 10
        AA = 0.8
      GO TO 12
   10   HO(INODE) = 0.
        AA = 0.
C
   12 PHI = S/VIN(INODE) + C1(INODE)*HO(INODE)/(1.-HO(INODE)*Z1)
      VEXP=1.08E-03
      TAVE=(TIN+TSATP)/2.
      PSI=S/(PJ*GO(INODE))+(PHI-S/VIN(INODE))*(1.-VEXP*TAVE)/DENSF
      HCQ=HO(INODE)/(1.-HO(INODE)*Z1)
      THETA = C18(INODE)*(AA/(1.-HO(INODE)*Z1) - 1.)
      BETA = C1(INODE)*CPF*Z2*HO(INODE)/(1. - HO(INODE)*Z1)
      NP1=NTOT(INODE)
      DO 50 I=1,NP1
      XIL(INODE,I)=CMPLX(0.,0.)
      U1(INODE,I)=CMPLX(0.,0.)
      U2(INODE,I)=CMPLX(0.,0.)
      U2S(INODE,I)=CMPLX(0.,0.)
      U3(INODE,I)=CMPLX(0.,0.)
   50 U4(INODE,I)=CMPLX(0.,0.)
      HSUM1 = CMPLX(0.,0.)
      NEND = NDP(INODE)
      DO 1 I=1,NEND
      HS(I) = CEXP(PHI*Z(INODE,I)) * (1.-CEXP(-PHI*DZ(INODE,I)))
      XIL(INODE,I)=HS(I)
      SL(I)=0.
      IF(I .EQ. NEND)SL(I)=1.
      HSUM1 = HSUM1 + HS(I)*QDIS(INODE,I)
      IM1=I-1
      IF(I .EQ. 1)GO TO 102
      XISUM=CMPLX(0.,0.)
      DO 101 IK=1,IM1
  101 XISUM=XISUM+HS(IK)*QDIS(INODE,IK)
      GO TO 103
  102 CONTINUE
      XISUM=CMPLX(0.,0.)
  103 CONTINUE
      XIK=CEXP(-PHI*Z(INODE,I))
      XI1=THETA/PHI*XIK/VIN(INODE)*XISUM
      U1(INODE,I)=Y1*QO(INODE,I)*HCQ/HO(INODE)*(AA/VIN(INODE)-
     @              HO(INODE)*XI1/(CPF*QO(INODE,I)))
      XI2=BETA/PHI*XIK
      U2(INODE,I)=-Y1*HCQ*XI2/CPF
      U2S(INODE,I)=Y1*HCQ*Z2+Y2
      U3(INODE,I)=-Y1*HCQ*XIK/CPF
      XI4=PSI/PHI*(1.-XIK)
      U4(INODE,I)=Y1*HCQ/CPF*((1.-VEXP*TAVE)-XI4)
    1 CONTINUE
      NTS=NEND+1
      H2KP(NTS)=CMPLX(1.,0.)
      DO 2 I=NTS,NP1
      U2S(INODE,I)=Y1*Z3(I)+Y2
    2 U4(INODE,I)=Y1*ZP(I)
      HSUM2 = CEXP(-PHI*XLAMB)
      CONBB = GO(INODE)*AXS(INODE)/(QO(INODE,NDP(INODE))*PH(INODE))
C
      TH1 = (THETA/PHI) * (HSUM2/VIN(INODE)) * HSUM1
      TH2 = (BETA/PHI) * HSUM2
      TH3 = HSUM2
      DO 11 I=1,NEND
   11 H2KP(I)=-TH2*HS(I)/(CPF*Z2)
C
      M1 = (-TH1+X2/DENSF) * CONBB
      M2 = -TH2 * CONBB
      M3 = -TH3 * CONBB
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      TH4=(PSI/PHI)*(1.-HSUM2)+TH1/DENSF*DRF-DHF1(P)
      PM4=-TH4*CONBB
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      IF(IOSUB .EQ. 0)GO TO 100
      QFLUX=QO(INODE,NEND)
      PE=GO(INODE)*DH(INODE)*CPF/KF
      SBX1=-.0022*DH(INODE)*CPF/KF
      SBX2=0.
      IF(PE .GE. 7.0E+04)GO TO 105
      GO TO 110
  105 SBX1=-154./GO(INODE)
      SBX2=154.*QFLUX/GO2(INODE)
  110 SM=QFLUX/(1.-HO(INODE)*Z1)
C
C
C
C
C
      S1=SM*(AA/VIN(INODE)-HO(INODE)*TH1/(CPF*QFLUX))
      S2=HCQ*Z2
      S3=-HCQ/CPF*TH3
      S4=HCQ/CPF*((1.-VEXP*TAVE)/DENSF-TH4)
      SH1=SBX1*S1+SBX2*DENSF
      SH2=SBX1*S2
      SH3=SBX1*S3
      SH4=SBX1*S4+SBX2*VIN(INODE)*DRF+DHF1(P)
      M1=-CONBB*(TH1-SH1)
      M3=-CONBB*(TH3-SH3)
      PM4=-CONBB*(TH4-SH4)
      M2=-CONBB*TH2
  100 CONTINUE
      RETURN
      END
C
C
C
C
C*********************************************************************
      SUBROUTINE STABTY(S,IK,RATIC,AMRAT,ARRAT,NCH1,ICOUNT,IBODE,IW,
     @                 JLL,JRR,ICASE)
C*****************************************************************************
C
C   * CALCULATE THE OPEN-LOOP TRANSFER FUNCTION.  GH(S)
C                *  RATION  =  GH(S)
C                *  AMRAT   =  ABS(GH(S))
C                *  ARRAT   =  ANG(GH(S))
C
      COMPLEX S,ZPK,RATIO,GAM1,GAM2,GAM3,PI1,PI2,PI3,TAU1,TAU2,TAU3
      COMPLEX F1,TGAM1,TPI1,FALF,AAA,F22,ZPKP,ZPK1,RATIO1
      COMPLEX CXL,CST1,CST2,CST3,RR1,RR2,RR3,DPUP1,DPUP2,DPUP3,
     1          DWSW1,DWSW2,DWSW3,T1,DPH1
      COMPLEX RAN1,GANM,ZN1,B1,RK1,XZN1,XBM,XRKM
      COMPLEX TZ1,TZ2,TWO,THREE,PWW1,PWW2,DWSW5,SUMPD,DPCORE,
     @         SUMPP,SUMSS,XJ,DPCORS
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMPLEX H,HHS,SHJ
      COMPLEX TALP2,TALP3,TALP4,TLP4,PM4,STC3,STC4,STC5,STC6,PP,
     1         SUMP,SUMP1,SUMSP,TEMPP,ASTAR,CSTAR,TLP,GAM2Q,HSQ
     2         ,PI2Q,T2Q,TALP1,GAM4,PI4,DWSW4,DPUP4,TSUM2,TP1
      COMPLEX GPI1,GPI2,GPI3,GPI4,QL1,QL2,QL3,QL4,QL2S,QL3S,QL4S,
     @         VJ1,VJ2,VJ3,WW1,WW2,WW1S,WW2S,HIN1S,HIN2S,BSTAR,
     @         QSTAR,SUM22S,SUM1,SUM21,SUM22,SUM42S,SUM3,SUM41,
     @         SUM42,SUMSPN,SUMP1N,SUMM
      COMPLEX GKJ,GKQ,GKH,GKP,GKJN,GKQN,GKHN,GKPN,THJ,THH,THQ,
     @         SUM1S,SUM3S,OPTK,OPTH,OPTJ,CLTK,GHJ1N,GHJ1,HJ,RATIOK,
     @         HJ1,SUMJ,RATIOP,PTOJ,RATIOW,OPTS,WC2P,Y
      COMPLEX XK,XKP,XKRA,XKPRA,SUMPQ,PSUMW(10),HJJT(5,5,30),
     @         HHT(5,30),T2T(5,30,5,30),U1,U2,U2S,U3,U4,XIL,
     @         TTJ,TTH,TTQ,TSTAR,ZPD,SUMXX
      COMPLEX SW1,SW2,SW3,SW4,ST1,ST2,ST3,ST4,SRHO1,SRHO2,SRHO3,
     @  SRHO4,TRANSP,HPP,XHH,XJPP(5),FW,FR,FRS,FJ,TRANSH,XHJ(5),
     @  SJ1,SJ2,SJ3,SJ4,PR1,PR2,PR3,PR3P,PR4,R1
      COMPLEX PKJ,PKQ,PKH,PKP,PHJ1,SHW
      COMPLEX GCS,GLS,PLS,H1J,GKJS,GKHS,GCJ,GCH,PIJ,PIH,PIC,GLJ,
     @         GLH,QJ,QH,PQ,PPJ,SPJ,SQ,PUP1,PUP2,PUP3,PUP4,GKJSN,
     @         GKHSN,HQ,HCJ,HCH
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      DIMENSION CAL1(30), CAL2(30),W(10,30),PHI(10,30),DELT(5,5)
C
      COMMON /PERT/ DELVI, DELQO, DELK,DELP
      COMMON/P1KO/ZPK, ZPK1, ZPKP, DRDU, VOCAL
      COMMON/P1K2/ZPD
      COMMON/WSW5/DWSW5
      COMMON/DPP/DPCORE,DPCORS
      COMMON /DPCON1/GAM1(5),GAM2(5,30),GAM3(5), PI1(5),
     1                PI2(5,30),PI3(5), TALP1(5,30),
     2                TSUM2(5,30),TAU1(5),TAU2(5),TALP3(5,30)
      COMMON /CXLP/ RR1(5), RR2, RR3, DPUP1(5), DPUP2, DPUP3,
     1               DWSW1(5), DWSW2(5,30),DWSW3,T1,DPH1,DPUP4
      COMMON/CONSS2/ NTOT(5),NBB(5),NBB1(5),NSP,NIPSP(5),
     1               K2PSP(5), NDP(5), NDP1(5), ISUB(5)
      COMMON/CONSS1/ QDIS(5,30),QO(5,30),DZ(5,30),Z(5,30),
     1       K1(5,30),CKIN(5,30),ZETA(5,30),DOIN(5,30),
     2       DOOUT(5,30),ALPIN(5,30),  BEE(5,30),CPI1(5,30),
     3       COR2PH(5,30), ZETSP(5,30), WIN
      COMMON/CONST2/ P,VCH,VIN(5),AXS(5),DH(5),DHIN(5),
     1     PH(5),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2     DENSF,VFG1,RHOG,GO(5),GO2(5),HO(5),GC,G1,KLOSS(30),
     3       FRICMO(5),VGJH(5,30),COH(5,30),CZERO,VGJ,DPTS,
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     4        GO2RF(5),HFG1,ZSP(30),NUMBSP(5,30),ALHEAT,CXF(5),
     5        AVEQ,CHOMO1,CHOMO2,XKIN(5),XKEXIT(5)
      COMMON /DIM1/ DELX,DELZ,CHLAMB(5),ALFNOD(5,30),BBLAMB(5)
      COMMON/VOIDPT/FALF(5,30),F1(5), TGAM1(5), TPI1(5)
      COMMON/SIM1/IMAX,JMAX,KMAX,IPASE,ISPEC,JSPEC,INUCLR,XKEFF
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMMON/MIMO/H(2,3)
      COMMON/YPR/PR1(5),PR2(5,30),PR3,PR3P,PR4
      COMMON/COREP/ STC3(30),STC4(30),STC5(30),STC6(30),PP(30),
     1               TALP2(5,30,30),TALP4(5,30),TLP4,PJ
      COMMON/STABP/ TLP,DWSW4
      COMMON/PPQQ/GAM4(5),PI4(5)
      COMMON/QQQ/Q3D(5,30)
      COMMON/MULT/NN(5)
      COMMON/SSS/GPI1(5),GPI2(5,30),GPI3(5),GPI4(5),
     @QL1(5),QL2(5,30),QL3,QL4,QL2S(5,30),QL3S(5),QL4S(5),
     @      VJ1(5),VJ2(5),VJ3(5),WW1(5),WW2,WW1S(5,5),
     @      WW2S(5),HIN1S(5),HIN2S
      COMMON/VEL/VEL3D(5)
      COMMON/TF/RATIOP,RATIOK,OPTK,OPTH,RATIOW,OPTJ,PTOJ,TRANSF,
     @          OPTS
      COMMON/SKIN/XK(5,30,5,30),XKP(5,30),XKRA(10,10),XKPRA(10)
      COMMON/GKIN/IKIN,IDCHTY(15,15),ITY(225),JJMX(15),JJDB(15,15),
     @              ITYB(150)
      COMMON/DPLER2/U1(5,30),U2(5,30),U2S(5,30),U3(5,30),U4(5,30),
     @              XIL(5,30)
      COMMON/SEPA/XINER,XLSEP,XKSEP,XASEP,XRHOS,ALPSEP,GOSEP,
     @              YLSEP,DHSEP,FSEP,CSEP,VSEP,CORPR
      COMMON/CSEPA/SW1(5),SW2(5,30),SW3,SW4,ST1(5),ST2(5,30),
     @              ST3,ST4,SRHO1(5),SRHO2(5,30),SRHO3,SRHO4,
     @              SJ1(5),SJ2(5,30),SJ3,SJ4
      COMMON/DSEPA/FW,FR,FRS,FJ
      COMMON/WET/EW(30)
      COMMON/SDOM/WC2P,AD1P,TURB,WTURB,ADOME,VDOME
      COMMON/POINTK/PKJ,PKQ,PKH,PKP,PHJ1,SHJ,SHW
      COMMON/YPUP/PUP1(5),PUP2(5,30),PUP3,PUP4
      COMMON/PHASOR/GCS(2),PLS(2),GLS(2),PIC(2)
C   QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      NCH=0
      DO 93 J=JLL,JRR
      NCH=NCH+NN(J)
   93 CONTINUE
      CHN=FLOAT(NCH)
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      SUMSP=CMPLX(0.,0.)
      SUMP1=CMPLX(0.,0.)
      GKJ=CMPLX(0.,0.)
      GKJS=CMPLX(0.,0.)
      GKQ=CMPLX(0.,0.)
      GKH=CMPLX(0.,0.)
      GKHS=CMPLX(0.,0.)
      GKP=CMPLX(0.,0.)
      GHJ1=CMPLX(0.,0.)
      DO 70 I=JLL,JRR
      NTS=NDP1(I)
      NP1=NTOT(I)
      NPM1=NP1-1
      SUMW=0.
      SUMP=0.
      IF(IW .NE. 0)GO TO 60
      DO 62 K=1,NP1
      W(I,K)=1.
      PHI(I,K)=1.
   62 CONTINUE
      GO TO 70
   60 DO 52 K=1,NP1
      W(I,K)=Q3D(I,K)**2
      SUMP=SUMP+Q3D(I,K)
      SUMW=SUMW+W(I,K)
   52 CONTINUE
      AVQ=SUMP/FLOAT(NP1)
      DO 54 K=1,NP1
      W(I,K)=W(I,K)/SUMW*FLOAT(NP1)
      PHI(I,K)=1.
   54 CONTINUE
   70 CONTINUE
      SUMV=0.
      DO 35 I=JLL,JRR
   35 SUMV=SUMV+VEL3D(I)*NN(I)
      SUMPQ=CMPLX(0.,0.)
      SUMH1M=CMPLX(0.,0.)
      DO 36 I=JLL,JRR
      SUMPQ=SUMPQ+QL1(I)/GPI1(I)*NN(I)
      SUMH1M=SUMH1M+HIN1S(I)*NN(I)
      PSUMW(I)=CMPLX(0.,0.)
      DO 37 M=JLL,JRR
   37 PSUMW(I)=PSUMW(I)+WW1S(I,M)
   36 CONTINUE
      DO 95 J1=JLL,JRR
      DO 95 L1=1,KMAX
      DO 95 J2=JLL,JRR
      DO 95 K2=1,KMAX
   95 T2T(J1,L1,J2,K2)=CMPLX(0.,0.)
      DO 96 J1=JLL,JRR
      DO 97 L1=1,KMAX
      DO 98 J2=JLL,JRR
      IF(L1 .EQ. 1)GO TO 97
      K2MAX=L1-1
      DO 99 K2=1,K2MAX
   99 T2T(J1,L1,J2,K2)=TALP2(J1,L1,K2)
   98 CONTINUE
   97 CONTINUE
   96 CONTINUE
      DO 31 I1=JLL,JRR
      DO 32 J1=JLL,JRR
      DELT(I1,J1)=0.
      IF(I1 .EQ. J1)DELT(I1,J1)=1.
   32 CONTINUE
   31 CONTINUE
      DO 55 J1=JLL,JRR
      DO 56 L1=1,KMAX
      HHT(J1,L1)=SUMPQ*HIN1S(J1)*GPI2(J1,L1)+SUMH1M*(QL2(J1,L1)-
     @    QL1(J1)/GPI1(J1)*GPI2(J1,L1))
   56 CONTINUE
   55 CONTINUE
      DO 59 I1=JLL,JRR
      DO 57 J1=JLL,JRR
      DO 58 L1=1,KMAX
      HJJT(I1,J1,L1)=GPI2(J1,L1)*(WW1S(I1,J1)*(1.+SUMPQ)+VJ1(I1)*
     @     DELT(I1,J1)*SUMPQ)+VJ1(I1)+PSUMW(I1)*(QL2(J1,L1)-QL1(J1)*
     @     GPI2(J1,L1)/GPI1(J1))
   58 CONTINUE
   57 CONTINUE
   59 CONTINUE
      DO 156 J1=JLL,JRR
      DO 156 L1=1,KMAX
      DO 156 J2=JLL,JRR
      DO 156 L2=1,KMAX
  156 XK(J1,L1,J2,L2)=TALP1(J1,L1)*HJJT(J1,J2,L2)+T2T(J1,L1,J2,L2)
     @                  +TALP3(J1,L1)*HHT(J2,L2)
      DO 158 JJ=JLL,JRR
      DO 158 KK=1,KMAX
  158 FALF(JJ,KK)=XK(JJ,KK,JJ,KK)
      DO 111 I1=JLL,JRR
      DO 112 L1=1,KMAX
      XKP(I1,L1)=TALP1(I1,L1)*WW2S(I1)+TALP3(I1,L1)*HIN2S+TALP4(I1,L1)
  112 CONTINUE
  111 CONTINUE
      VCORE=SUMV/CHN
      SUMJ=CMPLX(0.,0.)
      DO 72 I=JLL,JRR
      NTS=NDP1(I)
      NP1=NTOT(I)
      GKJN=CMPLX(0.,0.)
      GKJSN=CMPLX(0.,0.)
      GKQN=CMPLX(0.,0.)
      GKHN=CMPLX(0.,0.)
      GKHSN=CMPLX(0.,0.)
      GKPN=CMPLX(0.,0.)
      GHJ1N=CMPLX(0.,0.)
      SUMSPN=CMPLX(0.,0.)
      SUMP1N=CMPLX(0.,0.)
      DO 77 K=1,NP1
      THJ=CMFLX(0.,0.)
      THH=CMPLX(0.,0.)
      SUMM=CMPLX(0.,0.)
      TTJ=CMPLX(0.,0.)
      TTH=CMPLX(0.,0.)
      HJ1=CMPLX(0.,0.)
      XHH=CMPLX(0.,0.)
      DO 74 M=JLL,JRR
      SUM22S=CMPLX(0.,0.)
      SUM1S=CMPLX(0.,0.)
      DO 76 J=JLL,JRR
      NP1J=NTOT(J)
      NTSJ=NDP1(J)
      SUM1=CMPLX(0.,0.)
      SUM21=CMPLX(0.,0.)
      SUM22=CMPLX(0.,0.)
      DO 78 L=1,NP1J
      QSTAR=QL2(J,L)
      SUM1=SUM1+QSTAR*PHI(J,L)*QDIS(J,L)
      SUM22=SUM22+GPI2(J,L)*PHI(J,L)*QDIS(J,L)
   78 CONTINUE
      NP1M=NTOT(M)
      NTSM=NDP1(M)
      DO 82 L=1,NP1M
   82 SUM21=SUM21+GPI2(M,L)*PHI(M,L)*QDIS(M,L)
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```
      SUM1S=SUM1S+SUM1*NN(J)
      SUM22=(SUM21-SUM22)*QL1(J)/GPI1(J)
      IF(JRR .EQ. 1)GO TO 76
      IF(J .EQ. M)SUM22S=SUM22S+SUM22*(NN(J)-1)
      IF(J .NE. M)SUM22S=SUM22S+SUM22*NN(J)
   76 CONTINUE
      NP1P=NTOT(M)
      NTSP=NDP1(M)
      DO 115 L=1,NP1P
  115 SUM1S=SUM1S+GPI2(M,L)*PHI(M,L)*QDIS(M,L)
      SUMM=SUMM+(TALP1(I,K)*WW1S(I,M)+TALP3(I,K)*HIN1S(M))*
     @      (SUM1S+SUM22S)*NN(M)
      THJ=THJ+TALP1(I,K)*WW1S(I,M)*(SUM1S+SUM22S)*NN(M)
      HJI=HJI+WW1S(I,M)*(SUM1S+SUM22S)*NN(M)
      THH=THH+TALP3(I,K)*HIN1S(M)*(SUM1S+SUM22S)*NN(M)
      XHH=XHH+HIN1S(M)*(SUM1S+SUM22S)*NN(M)
      TTJ=TTJ+U1(I,K)*WW1S(I,M)*(SUM1S+SUM22S)*NN(M)
      TTH=TTH+U3(I,K)*HIN1S(M)*(SUM1S+SUM22S)*NN(M)
   74 CONTINUE
      SUM42S=CMPLX(0.,0.)
      DO 84 J=JLL,JRR
      NP1JJ=NTOT(J)
      NTSJJ=NDP1(J)
      SUM3=CMPLX(0.,0.)
      SUM41=CMPLX(0.,0.)
      SUM42=CMPLX(0.,0.)
      SUM3S=CMPLX(0.,0.)
      DO 86 L=1,NP1JJ
      QSTAR=QL2(J,L)
      SUM3=SUM3+QSTAR*PHI(J,L)*QDIS(J,L)
      SUM42=SUM42+GPI2(J,L)*PHI(J,L)*QDIS(J,L)
   86 CONTINUE
      DO 88 L=1,NP1
   88 SUM41=SUM41+GPI2(I,L)*PHI(I,L)*QDIS(I,L)
      SUM3S=SUM3S+SUM3*NN(J)
      SUM42=(SUM41-SUM42)*QL1(J)/GPI1(J)
      IF(JRR .EQ. 1)GO TO 89
      IF(J .EQ. I)SUM42S=SUM42S+SUM42*(NN(J)-1)
      IF(J .NE. I)SUM42S=SUM42S+SUM42*NN(J)
   84 CONTINUE
   89 CONTINUE
      DO 114 L=1,NP1
  114 SUM3S=SUM3S+GPI2(I,L)*PHI(I,L)*QDIS(I,L)
      SUM3S=SUM3S+SUM42S
      THJ=THJ+TALP1(I,K)*VJ1(I)*SUM3S
      HJI=HJI+VJ1(I)*SUM3S
      XHJ(I)=HJI
      TTJ=TTJ+U1(I,K)*VJ1(I)*SUM3S
      KLOW=K-1
      CSTAR=CMPLX(0.,0.)
      THQ=CMPLX(0.,0.)
      TTQ=CMPLX(0.,0.)
      IF(KLOW .LE. 0)GO TO 83
      DO 81 JJ=1,KLOW
      THQ=THQ+TALP2(I,K,JJ)*PHI(I,JJ)*QDIS(I,JJ)
      TTQ=TTQ+U2(I,K)*XIL(I,JJ)*PHI(I,JJ)*QDIS(I,JJ)
   81 CSTAR=CSTAR+TALP2(I,K,JJ)*PHI(I,JJ)*QDIS(I,JJ)
   83 CONTINUE
      CSTAR=CSTAR+SUMM+TALP1(I,K)*VJ1(I)*SUM3S
      BSTAR=TALP4(I,K)+TALP3(I,K)*HIN2S+TALP1(I,K)*WW2S(I)
      TSTAR=U4(I,K)+U3(I,K)*HIN2S+U1(I,K)*WW2S(I)
      SUMSPN=SUMSPN+ZPK/(CHN*ALHEAT)*W(I,K)*BSTAR*DZ(I,K)
      SUMP1N=SUMP1N+ZPK/(CHN*ALHEAT)*W(I,K)*CSTAR*DZ(I,K)
      GKJN=GKJN+ZPK/(CHN*ALHEAT)*W(I,K)*THJ*DZ(I,K)
      GKQN=GKQN+ZPK/(CHN*ALHEAT)*W(I,K)*THQ*DZ(I,K)
      GKHN=GKHN+ZPK/(CHN*ALHEAT)*W(I,K)*THH*DZ(I,K)
      GKHSN=GKHSN+ZPK/(CHN*ALHEAT)*W(I,K)*TALP3(I,K)*DZ(I,K)
      GKPN=GKPN+ZPK/(CHN*ALHEAT)*W(I,K)*BSTAR*DZ(I,K)
      GKJN=GKJN+ZPD/(CHN*ALHEAT)*W(I,K)*TTJ*DZ(I,K)
      GKQN=GKQN+ZPD/(CHN*ALHEAT)*W(I,K)*TTQ*DZ(I,K)
      GKHN=GKHN+ZPD/(CHN*ALHEAT)*W(I,K)*TTH*DZ(I,K)
      GKPN=GKPN+ZPD/(CHN*ALHEAT)*W(I,K)*TSTAR*DZ(I,K)
      GHJ1N=GHJ1N+ZPK/(CHN*ALHEAT)*W(I,K)*TALP1(I,K)*
     @       VEL3D(I)*DZ(I,K)
      GKJSN=GKJSN+GHJ1N/VCORE
   77 CONTINUE
      SUMSP=SUMSP+SUMSPN*NN(I)
      SUMP1=SUMP1+SUMP1N*NN(I)
      SUMJ=SUMJ+HJ1*VEL3D(I)/VCORE*NN(I)
      GKJ=GKJ+GKJN*NN(I)
      GKJS=GKJS+GKJSN*NN(I)
      GKP=GKP+GKPN*NN(I)
      GKQ=GKQ+GKQN*NN(I)
      GKH=GKH+GKHN*NN(I)
      GKHS=GKHS+GKHSN*NN(I)
      GHJ1=GHJ1+GHJ1N*NN(I)
   72 CONTINUE
      RATIO=SUMSP/(1.-SUMP1)
      RATIOP=GKP/(1.-(GKJ+GKQ+GKH))
      RATIOK=ZPK1/(1.-(GKJ+GKQ+GKH))
      OPTK=-(GKJ+GKQ+GKH)
      OPTH=-GKH/(1.-(GKJ+GKQ))
      HJ=GHJ1/(1.-(GKQ+GKH))
      OPTJ=-HJ*SUMJ/(CHN*VCORE)
      PTOJ=SUMJ/(CHN*VCORE)
      HPP=XHH*RATIOP+HIN2S
      SUM1=CMPLX(0.,0.)
      SUM1S=CMPLX(0.,0.)
      SUMSS=CMPLX(0.,0.)
      SUMPD=CMPLX(0.,0.)
      SUMPP=CMPLX(0.,0.)
      SHW=CMPLX(0.,0.)
      DO 160 I=JLL,JRR
      XJPP(I)=XHJ(I)*RATIOP+WW2S(I)
      XJ=XHJ(I)*RATIOP
      SUM1=SUM1+DENSI*AXS(I)*XHJ(I)*NN(I)
      SHW=SHW+DENSI*AXS(I)*WW2S(I)*NN(I)
      SUM1S=SUM1S+DENSI*AXS(I)*XJPP(I)*NN(I)
      SUMSS=SUMSS+DENSI*AXS(I)*XJ*NN(I)
      SUMPD=SUMPD+QL1(I)*XJPP(I)*NN(I)
      SUMPP=SUMPP+QL1(I)*XJ*NN(I)
      NP1=NTOT(I)
      DO 262 KK=1,NP1
      SUMPP=SUMPP+QL2(I,KK)*QDIS(I,KK)*RATIOP*NN(I)
  262 SUMPD=SUMPD+QL2(I,KK)*QDIS(I,KK)*RATIOP*NN(I)
  160 CONTINUE
      SHJ=SUM1
      H(1,3)=SUM1S
      SUMPD=SUMPD+QL3*HPP+QL4+DWSW5*H(1,3)
      DPCORE=-SUMPD
      SUMPP=SUMPP+QL3*(HPP-HIN2S)+DWSW5*SUMSS
      DPCORS=-SUMPP
      HHS=HJ*SHJ/WIN
      OPTJ=-HHS
      H(1,3)=H(1,3)/WIN*P
      H(1,1)=HHS/(1.-HHS)
      H(1,2)=RATIOK*SHJ/WIN
      H(2,1)=HJ/((1.-HHS)*WIN*ZPK1)*WIN
      RATIOW=ZPK1*H(2,1)
      H(2,2)=-RATIOK*OPTK/ZPK1
      H(2,3)=(-OPTK*RATIOP+GKP)/ZPK1*P
      PKJ=GKJ/ZPK
      PKQ=GKQ/ZPK
      PKH=GKH/ZPK
      PKF=GKP/ZPK
      PHJ1=GHJ1/ZPK
      SUM1=CMPLX(0.,0.)
      SUM1S=CMPLX(0.,0.)
      DO 161 I=JLL,JRR
      SUM1=SUM1+SW1(I)*XJPP(I)*NN(I)
      NP1=NTOT(I)
      SUM3=CMPLX(0.,0.)
      DO 162 KK=1,NP1
  162 SUM3=SUM3+SW2(I,KK)*PHI(I,KK)*QDIS(I,KK)*RATIOP
      SUM1S=SUM1S+SUM3*NN(I)
  161 CONTINUE
      FW=SUM1+SUM1S+SW3*HPP+SW4
      SUM1=CMPLX(0.,0.)
      SUM1S=CMPLX(0.,0.)
      DO 163 I=JLL,JRR
      SUM1=SUM1+ST1(I)*XJPP(I)*NN(I)
      NP1=NTOT(I)
      SUM3=CMPLX(0.,0.)
      DO 164 KK=1,NP1
  164 SUM3=SUM3+ST2(I,KK)*PHI(I,KK)*QDIS(I,KK)*RATIOP
      SUM1S=SUM1S+SUM3*NN(I)
  163 CONTINUE
      FR=SUM1+SUM1S+ST3*HPP+ST4
      SUM1=CMPLX(0.,0.)
      SUM1S=CMPLX(0.,0.)
      DO 165 I=JLL,JRR
      SUM1=SUM1+SRHO1(I)*XJPP(I)*NN(I)
      NP1=NTOT(I)
      SUM3=CMPLX(0.,0.)
      DO 166 KK=1,NP1
  166 SUM3=SUM3+SRHO2(I,KK)*PHI(I,KK)*QDIS(I,KK)*RATIOP
      SUM1S=SUM1S+SUM3*NN(I)
  165 CONTINUE
      FRS=SUM1+SUM1S+SRHO3*HPP+SRHO4
      SUM1=CMPLX(0.,0.)
      SUM1S=CMPLX(0.,0.)
      DO 167 I=JLL,JRR
      SUM1=SUM1+SJ1(I)*XJPP(I)*NN(I)
      NP1=NTOT(I)
      SUM3=CMPLX(0.,0.)
      DO 168 KK=1,NP1
  168 SUM3=SUM3+SJ2(I,KK)*PHI(I,KK)*QDIS(I,KK)*RATIOP
      SUM1S=SUM1S+SUM3*NN(I)
  167 CONTINUE
      FJ=SUM1+SUM1S+SJ3*HPP+SJ4
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      SUM1=CMPLX(0.,0.)
      SUM1S=CMPLX(0.,0.)
      DO 177 I=JLL,JRR
      SUM1=SUM1+PR1(I)*XJPP(I)*NN(I)
      NP1=NTOT(I)
      SUM3=CMPLX(0.,0.)
      DO 178 KK=1,NP1
  178 SUM3=SUM3+PR2(I,KK)*PHI(I,KK)*QDIS(I,KK)*RATIOP
      SUM1S=SUM1S+SUM3*NN(I)
  177 CONTINUE
      RI=CMPLX(0.,0.)
      DRHOG=-DVG1(P)/(VFG(P)+VF(P))**2
      Y=FR-H(1,3)*WIN/P-(1.-RHOG*ADOME/(DENSI*AD1P))*
     @  (FW-H(1,3)*WIN/P+WC2P)-S*VDOME*DRHOG
      OPTS=-TURB*WTURB/Y
      TRANSP=RATIOP/(Y-TURB*WTURB)
      DO 312 JX=JLL,JRR
      NTS=NDP1(JX)
      NP1=NTOT(JX)
      XKPRA(JX)=CMPLX(0.,0.)
      DO 313 KX=1,NP1
      XKPRA(JX)=XKPRA(JX)+XKP(JX,KX)*W(JX,KX)*DZ(JX,KX)/ALHEAT
  313 CONTINUE
      DO 3121 JY=JLL,JRR
      NTSY=NDP1(JY)
      NP1Y=NTOT(JY)
      XKRA(JX,JY)=CMPLX(0.,0.)
      SUMXX=CMPLX(0.,0.)
      DO 3123 KY=1,NP1Y
      DO 3122 KX=1,NP1
 3122 SUMXX=SUMXX+XK(JX,KX,JY,KY)*
     @               W(JX,KX)*DZ(JX,KX)/ALHEAT
 3123 XKRA(JX,JY)=XKRA(JX,JY)+SUMXX*W(JY,KY)*DZ(JY,KY)/ALHEAT
 3121 CONTINUE
  312 CONTINUE
      DO 159 JJ=JLL,JRR
  159 F1(JJ)=XKRA(JJ,JJ)
C
      AVEM=0.
      PPJ=CMPLX(0.,0.)
      SPJ=CMPLX(0.,0.)
      PQ=CMPLX(0.,0.)
      SQ=CMPLX(0.,0.)
      DO 120 I=JLL,JRR
      NP1=NTOT(I)
      VRATIO=VEL3D(I)/VCORE
      AVEM=AVEM+DENSI*AXS(I)*VRATIO*NN(I)
      PPJ=PPJ+(PUP1(I)+PR1(I))*VRATIO*NN(I)
      SPJ=SPJ+DWSW1(I)*VRATIO*NN(I)
      DO 122 K=1,NP1
      PQ=PQ+(PUP2(I,K)+PR2(I,K))*QDIS(I,K)*NN(I)
  122 SQ=SQ+DWSW2(I,K)*QDIS(I,K)*NN(I)
  120 CONTINUE
      HQ=CMPLX(0.,0.)
      GQ=CMPLX(0.,0.)
      I=1
      NP1=NTOT(I)
      DO 124 K=1,NP1
      HQ=HQ+P12(I,K)*QDIS(I,K)
  124 GQ=GQ+GAM2(I,K)*QDIS(I,K)
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      H1J=TLP*AVEM
      DO 126 II=1,2
      QJ=CMPLX(0.,0.)
      QH=CMPLX(0.,0.)
      IF(II .EQ. 2)GO TO 127
      QJ=HJ/VCORE
  127 CONTINUE
      GCJ=GAM1(I)*VEL3D(I)/VCORE+GQ*QJ
      HCJ=PI1(I)*VEL3D(I)/VCORE+HQ*QJ
      GCH=GQ*QH+GAM3(I)
      HCH=HQ*QH+PI3(I)
      GCS(II)=GCJ+GCH*H1J
      PIC(II)=HCJ+HCH*H1J
      PIJ=PPJ+PQ*QJ
      PIH=PUP3+PR3+PQ*QH
      PLS(II)=PIC(II)+PIJ+PIH*H1J
      GLJ=SPJ+SQ*QJ
      GLH=DWSW3+SQ*QH
      GLS(II)=GCJ+GLJ+(GCH+GLH)*H1J
      GLS(II)=GLS(II)+DWSW5*AVEM
  126 CONTINUE
 1000 CONTINUE
      RETURN
      END
C
C
CC%%%%%%%%%%C%%CC%C%%C%C%@/@/@/@/@/@/@/@/@/@/@/@/@/@/@/@/@/@/@
C
      SUBROUTINE ASSIGN(N1, N2, X, IND, INODE, IB)
C
C     *  NODE REDISTRIBUTION
C
      DIMENSION XDZ(30), XQDIS(30), XCO(30), XVGJ(30)
      COMMON/CONSS1/ QDIS(5,30), QO(5,30), DZ(5,30),Z(5,30),
     1        K1(5,30), CKIN(5,30), ZETA(5,30), DOIN(5,30),
     2        DOOUT(5,30), ALPIN(5,30),BEE(5,30), CPI1(5,30),
     3        COR2PH(5,30), ZETSP(5,30), WIN
      COMMON/CONST2/ P,VCH,VIN(5),AXS(5),DH(5),DHIN(5),
     1        PH(5),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,XF,
     2        DENSF,VFG1,RHOG,GO(5),GO2(5),HO(5),GC,G1,XLOSS(30),
     3        FRICMO(5),VGJH(5,30),COH(5,30),CZERO,VGJ,DPTS,
     4        GO2RF(5),HFG1,ZSP(30),NUMBSP(5,30),ALHEAT,CXF(5),
     5        AVEQ,CHOMO1,CHOMO2,XKIN(5),XKEXIT(5)
C
      DO 100 I=N1,N2
        XDZ(I) = DZ(INODE,I)
        XQDIS(I) = QDIS(INODE,I)
        IF(IB .EQ. 0) GO TO 100
        XCO(I) = COH(INODE,I)
        XVGJ(I) = VGJH(INODE,I)
  100 CONTINUE
C
      NBB2 = N1 - 1
      INN1 = N1 + 1
      INN2 = N2 + 1
      NBBS = INN1 + 1
      DO 101 I=INN1,INN2
        IN = I - 1
        QDIS(INODE,I) = XQDIS(IN)
        IF(IB .EQ. 0) GO TO 103
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```
        COH(INODE,I) = XCO(IN)
        VGJH(INODE,I) = XVGJ(IN)
  103  IF(I .EQ. INN1) GO TO 101
        DZ(INODE,I) = XDZ(IN)
  101 CONTINUE
C
      IF(IND .EQ. 0) GO TO 500
      GO TO 200
  500 IF(NBB2 .NE. 0) GO TO 200
        DZ(INODE,N1) = X
        Z(INODE,N1) = X
        DZ(INODE,INN1) = XDZ(N1) - DZ(INODE,N1)
        Z(INODE,INN1) = Z(INODE,N1) + DZ(INODE,INN1)
      GO TO 201
  200   DZ(INODE,N1) = X - Z(INODE,NBB2)
        Z(INODE,N1) = Z(INODE,NBB2) + DZ(INODE,N1)
        DZ(INODE,INN1) = XDZ(N1) - DZ(INODE,N1)
        Z(INODE,INN1) = Z(INODE,N1) + DZ(INODE,INN1)
C
  201 DO 102 I=NBBS,INN2
        IN = I- 1
        Z(INODE,I) = Z(INODE,IN) + DZ(INODE,I)
  102 CONTINUE
      RETURN
      END
C
C
C
C
C******************************************************************
      SUBROUTINE DPLP(ICAL,JLL,JRR,S,ICASE)
C******************************************************************
C
C    * CALCULATE THE PRESSURE DROP PERTURBATION IN THE LOOP
C
      REAL KF,KLOSS,K1
      COMPLEX HUB1(5),HUB2(5),RR1,RR2,RR3,CX12(5),RT1,RT2,
     1        DPUP1,DPUP2,DPUP3,CX7(5),CX8(5),CX9,CX10,CX11,
     2        SH1,SH2,SH3,SH5,UPC1,UPC2, CXJ1,CXJ2,CXJ3, CXA1,CXA2,
     3        CXA3, SUP1(5),SUP2(5),SUP3(5),SUPT, CR1,CR2,RX2,
     4        DWSW1,DWSW2,DWSW3, T1, CC1,CC2,CC7,EPV,WC1,WC2, DTHET,
     5        DPIZ,DPIE,DDD, TLP1,TLP2, DPH1, S, RX1, SUP5,PDWSW2
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMPLEX M1,M2,M3,M4,TH1,TH2,TH3,GAM1,GAM2,GAM3,PI1,PI2,PI3
      COMPLEX STC1,STC2,CSTB1,CSTB2,Z3,HS,TG,TB1,TB2,TF,TR1,TR2,Z1,
     1        Z2,TALP1,TALP2,TALP3, TSUM2, TAU1,TAU2,PSUM,VPL
      COMPLEX ROPA,ROPJ,RX3,SUPT3P,PR1,PR2,PR3,PR3P,PR4
      COMPLEX CXJ4,CXA4,CX13
      COMPLEX PM4,GAM4,CLTX,EDP1,EDP2,EDP3,CSB9PP,TLP,DWSW4
      COMPLEX SPT4,SPK4(30),CKI41(30),CKI42(30),B4,PP,PAR4(30),
     1        SPA4,SPB4,SUMP4,PINOD4(30),TALP4,PP6,PAR4P,
     2        VAR4P,GT2P,PP1P,DP1P,DP2P,DP3P,DP4P,DP5P,DP6P,DP7P,
     3        DP8P,DP9P,DP10P,DP11P,DP12P,DP13P,DP14P,DP15P,
     4        STC3,STC4,STC5,STC6,
     5        CD(30),CX4(30),PI4,SUM7P,DP16P,DP17P
      COMPLEX PP3,SUP3P,RO14,RO24,CLP1,CLP2,CLP3,CLP4,CLP5,CLP6,
     1        CLP7,CLP8,WP1,WP2,WP3,CRP1,CRP2,CRP3,CRP4,CRP6,CRP7,
     2        CRP9,CRP10,ROA,ROB,RR4,DGAMP
      COMPLEX DPUP4,TLP4,DWSW4P,SH6,EEE,DFE,AUP1,UPP1
      COMPLEX SBJ4(30),SBM4(30),SUMS5P,SUMS4P,SBZP(30),
     1        SUM3P,SUM4P,U6K,SC17,SC18,SC19,SC20,SC21,
     2        SC22,A06,A07,SINO,SIN13,SIN12,
     3        SC3P1,SC3P21,SC3P2,SC3P,SK14(30)
      COMPLEX PPS,PPSP,OMH,PC4,CK142S,SK14S,CW,CW2,OMEGA
     @        ,STOM,STOM2,CSBX3,ZP,AJUP,AAUP,APUP,UPEP,C1UP
     @        ,C2UP,DGDP,UP1P,UP2P,UP3P,A2A,ST2V,ST21,PSJ4
      COMPLEX PUP1,PUP2,PUP3,PUP4,A4P,DP1,CC4,SH4,DWSW21,TH4,CC3
      COMPLEX UPW,AJRP,AARP,APRP,AJR,AAR,APR,R1P,R2P,R3P,R4P,
     @        BJ,BQ,BH,BP,AKJ,AKQ,AKH,AKP,DWSW5,GPI1,GPI2,GPI3,
     @        GPI4,QL1,QL2,QL3,QL4,QL2S,QL3S,QL4S,VJ1,VJ2,VJ3,
     @        WW1,WW2,WW1S,WW2S,HIN1S,HIN2S,SUMV3,SUMV2,
     @        GPI3S(200),GPI4S(200)
      COMPLEX UPEPR,UPA1,UPA2,C2R,V3P,GPS,CR6S,AJRPP,AARPP,APRPP,
     @        UPREP,XJ2R,XJ3R,XK2R,XK3R,UPJ2S,UPA2S
      COMPLEX C1R,PCL1,PCL2,PCL3,PCL4,XJ1RS,XJ2RS,XJ3RS,
     @        XK1RS,XK2RS,XK3RS,DGDPR
      COMPLEX SW1,SW2,SW3,SW4,ST1,ST2,ST3,ST4,SRHO1,SRHO2,SRHO3,
     @        SRHO4,SJ1,SJ2,SJ3,SJ4,FW,FR,FRS,FJ
      COMPLEX Q1,Q2,R1,R2,WC1P,WC2P
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      COMMON/PDWSW/PDWSW2
      COMMON/OPTION/ IOSUB, IOHW, IO2Q, IPILO, ISLIP, IRW
      COMMON/CONST1/ C1(5),C2(5),C3(5),C4,C5(5),C8(5,30),
     1       C9(5,30),C18(5), C21(5), C22(5),C25(5),
     2       C26(5), T6, V7(5), DD1, CKI, CMP
      COMMON/CONST2/ P,VCH,VIN(5),AXS(5),DH(5),DHIN(5),
     1       PH(5),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2       DENSF,VFG1,RHOG,G0(5),G02(5),H0(5),GC,G1,KLOSS(30),
     3       FRICMO(5),VGJH(5,30),COH(5,30),CZERO,VGJ,DPTS,
     4       G02RF(5),HFG1,ZSP(30),NUMBSP(5,30),ALHEAT,CXF(5),
     5       AVEQ,CHOMO1,CHOMO2,XKIN(5),XKEXIT(5)
      COMMON/CONSS1/ QDIS(5,30), Q0(5,30), DZ(5,30),Z(5,30),
     1       K1(5,30), CKIN(5,30), ZETA(5,30), DOIN(5,30),
     2       DOOUT(5,30), ALPIN(5,30),BEE(5,30), CPI1(5,30),
     3       COR2PH(5,30), ZETSP(5,30), WIN
      COMMON/CONSS2/ NTOT(5),NDB(5),NDB1(5),NSP,N1PSP(5),
     1               K2PSP(5), NDP(5), NDP1(5), ISUB(5)
      COMMON /RISER/ COR,VGJR,CKRO,RL,AR,DRIN,DR,PI,CL1,CL2,CL3,CL4,
     1        CL5, CL6, CR5, CR6, UPJ1(5), UPJ2(5), RO11, RO12,
     2               RO21, RO22, XROUT, UPJIN
      COMMON/CLOOP/ SLOOP, SFLOOP, RLOOP,AA,
     @               VL1(5), VL2(5), VL3(5), DPLPT,RATW
      COMMON/CUPPER/RKIN,RKEXIT,AP,RPO,RP1,RP2,CL10(5),CL11(5),
     1                CLT,AXSCH,RAR,AD,DL,DHDL,FDL, F1(5),F2(5),
     2                RJ1(5),RJ2(5),RJ3(5),F3(5)
      COMMON /CDELH1/ HFW, ADC, PHV, DKV, CPV, DENV, TEMV, TEMINV,
     1                THV, HOD, PLM, AHLP, THLP, HOLP, WO, DLENG
      COMMON /CDELH2/ CH1, CH2, CH3, CH4, CH5, CH7, CH8, CH9, CH10
      COMMON /CXCH/ CXJ1(5),CXJ2(5,30),CXJ3(5), CXA1(5),
     1               CXA2(5,30),CXA3(5)
      COMMON /CXLP/ RR1(5), RR2, RR3, DPUP1(5), DPUP2, DPUP3,
     1               DWSW1(5),DWSW2(5,30),DWSW3,T1,DPH1,DPUP4
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMMON/COREP/ STC3(30),STC4(30),STC5(30),STC6(30),PP(30),
     1               TALP2(5,30,30),TALP4(5,30),TLP4,PJ
      COMMON/DELTAP/DGAMP,DRHOG,DHF,DHG,DCZERO,DVGJ,DCOR,DVGJR
      COMMON/RISERP/CLTX,RR4,CRP5,CRP8,RO13,RO23,CL12,UPJ3,ALPRO,
     1               GOR,RHOR,VRO,CRCON,UPALP
      COMMON/STABP/ TLP,DWSW4
      COMMON /DPCON1/GAM1(5),GAM2(5,30),GAM3(5), PI1(5),
     1                  P12(5,30),P13(5),  TALP1(5,30),
     2                  TSUM2(5,30),TAU1(5),TAU2(5),TALP3(5,30)
      COMMON/PCXCH/CXJ4(5),CXA4(5)
      COMMON/PCON2P/PPS(30)
      COMMON/PPQQ/GAM4(5),P14(5)
      COMMON/PSP/CSBX3(5,30),ALOUT(5,30)
      COMMON/YYY/ZLUP,FLUP,GOU,DHUP,ROUP,FUP,ZLR,FLR,ROR,FRR
     @           ,ADLP,DHLP,ZLLP,FLLP,XKLP,GOLP,FLP
     @           ,AD1,DH1,ZL1,FL1,XK1,GO1,FD1
     @           ,AD2,DH2,ZL2,FL2,XK2,GOD2,FD2
     @           ,AD3,DH3,ZL3,FL3,XK3,GO3,FD3
     @           ,SPUMP,CPUMP
      COMMON/SEPA/XINER,XLSEP,XKSEP,XASEP,XRHOS,ALPSEP,GOSEP,
     @             YLSEP,DHSEP,FSEP,CSEP,VSEP,CORPR
      COMMON/CSEPA/SW1(5),SW2(5,30),SW3,SW4,ST1(5),ST2(5,30),
     @              ST3,ST4,SRHO1(5),SRHO2(5,30),SRHO3,SRHO4,
     @              SJ1(5),SJ2(5,30),SJ3,SJ4
      COMMON/DSEPA/FW,FR,FRS,FJ
      COMMON/SDOM/WC2P,AD1P,TURB,WTURB,ADOME,VDOME
      COMMON/PGAM/IGAM,IDRF
      COMMON/YPR/PR1(5),PR2(5,30),PR3,PR3P,PR4
      COMMON/RNEW/F3P,RJ3P
      COMMON/YPUP/PUP1(5),PUP2(5,30),PUP3,PUP4
      COMMON/CPBOIL/M1,M2,M3,TH1,TH2,TH3,HS(30),PM4,TH4
      COMMON/PCHOUT/XCHOUT(5),ACHOUT(5),CCHOUT(5)
      COMMON/MULT/NN(5)
      COMMON/MULTW/UPJW(5),CLW(5),PJOUT(5)
      COMMON/UPJA/BJ(5),BQ(5,30),AKJ(5),AKQ(5,30)
      COMMON/WSW5/DWSW5
C   QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      DRF=DRFDP(P)
      IF(IDRF .EQ. 0)DRF=0.
      DDR=DRGDP(P)-DRF
      DRGFP=DRGDP(P)-RHOG/DENSF*DRF
C
      DO 1 I=JLL,JRR
      NP1 = NTOT(I)
      HUB1(I) = CMPLX(0.,0.)
      HUB2(I) = CMPLX(0.,0.)
       DO 2 J=1,NP1
       HUB1(I) = HUB1(I) + CXJ2(I,J)*BEE(I,J)
       HUB2(I) = HUB2(I) + CXA2(I,J)*BEE(I,J)
    2  CONTINUE
    1 CONTINUE
C     1) FOR THE UPPER PLENUM
C
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C      NEW PRESSURE DROP PERTURBATION IN THE UPPER PLENUM
      FUP1=ZLUP/AP
      AJUP=CMPLX(0.,0.)
      UPEP=CEXP(-(S*ZLUP/UPJIN))
      DGDP=S/HFG1*(1./PJ-DENSF*(1.-UPALP)*DHF1(P)-RHOG*UPALP
     @ *DHG1(P))
      C1UP=VFG1*DGDP-UPALP/RHOG*S*DRHOG-(1.-UPALP)/DENSF*S*DRF
      C2UP=DGDP/RHOG-UPALP/RHOG*S*DRHOG-UPALP*C1UP
      DPR=RP1-RP2
      UPEPR=CEXP(-(S*DPR/UPJIN))
      UPA1=-G1*C4*UPJIN/S*(1.-UPEPR)
      UPA2=G1*DPR*(DRF+UPALP*DDR-C4*C2UP/S)+G1*C4*C2UP*UPJIN/S**2
     @      *(1.-UPEPR)
```

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      UPA2=UPA1*C2UP/S*(1.-UPEP)+UPA2
      UPA1=UPA1*UPEP
      AAUP=-C4*(1.-UPEP)*G1*UPJIN/S
      APUP=-C2UP/S*AAUP+G1*ZLUP*(UPALP*DDR-C4*C2UP/S+DRF)+UPA2
      AAUP=AAUP+UPA1
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      UPC1 = -S*(RP2-ALHEAT)/UPJIN
      UPC2 = (GC*C4*UPJIN/G1/S) * (CEXP(UPC1)-1.)
      DPUP2 = CMPLX(0.,0.)
      DPUP3 = CMPLX(0.,0.)
      PUP3=CMPLX(0.,0.)
      PUP4=CMPLX(0.,0.)
      UP3P=CMPLX(0.,0.)
      BH=CMPLX(0.,0.)
      BP=CMPLX(0.,0.)
      AKH=CMPLX(0.,0.)
      AKP=CMPLX(0.,0.)
      DO 12 I=JLL,JRR
      DPUP1(I) = ((F1(I)*CXJ1(I) + F2(I)*CXA1(I))/AXS(I)/DENSF +
     1            F3(I)) * UPC2
      DPUP2 = DPUP2 + (F1(I)*HUB1(I) + F2(I)*HUB2(I))*UPC2
      DPUP3 = DPUP3 + (F1(I)*CXJ3(I) + F2(I)*CXA3(I))*UPC2
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      UPW=1./GC*(AJUP*UPJW(I)+AAUP*CLW(I))
      UP1P=1./GC*(AJUP*UPJ1(I)+AAUP*CL11(I))+UPW*DENSF*AXS(I)
      UP2P=1./GC*(AJUP*UPJ2(I)+AAUP*CL10(I))
      NP1=NTOT(I)
      PJOUT(I)=(CCHOUT(I)-VGJH(I,NP1))/COH(I,NP1)
      GPJ=ACHOUT(I)*CCHOUT(I)*DDR-ACHOUT(I)*C4*(DCZERO*PJOUT(I)+
     @       DVGJ)
      DENUP=DENSF-C4*COH(I,NP1)*ACHOUT(I)
      UPJ2S=UPJ2(I)-UPJW(I)*AXS(I)*C4*CCHOUT(I)
      UPA2S=CL10(I)-CLW(I)*AXS(I)*C4*CCHOUT(I)
      BJ(I)=(UPJ1(I)+UPJW(I)*DENUP*AXS(I))*CXJ1(I)+UPJ2S*CXA1(I)
      BH=BH+((UPJ1(I)+UPJW(I)*DENUP*AXS(I))*CXJ3(I)+UPJ2S*CXA3(I))
     @   *NN(I)
      BP=BP+((UPJ1(I)+UPJW(I)*DENUP*AXS(I))*CXJ4(I)+UPJ2S*CXA4(I)+
     @   UPJW(I)*PJOUT(I)*AXS(I)*DRF)*NN(I)
      BP=BP+UPJW(I)*AXS(I)*GPJ*NN(I)
      DO 85 J=1,NP1
      BQ(I,J)=(UPJ1(I)+UPJW(I)*DENUP*AXS(I))*CXJ2(I,J)+UPJ2S
     @        *CXA2(I,J)
      AKQ(I,J)=(CL11(I)+CLW(I)*DENUP*AXS(I))*CXJ2(I,J)+UPA2S
     @        *CXA2(I,J)
   85 CONTINUE
      AKJ(I)=(CL11(I)+CLW(I)*DENUP*AXS(I))*CXJ1(I)+UPA2S*CXA1(I)
      AKH=AKH+((CL11(I)+CLW(I)*DENUP*AXS(I))*CXJ3(I)+UPA2S*
     @    CXA3(I))*NN(I)
      AKP=AKP+((CL11(I)+CLW(I)*DENUP*AXS(I))*CXJ4(I)+UPA2S*
     @    CXA4(I)+CLW(I)*PJOUT(I)*AXS(I)*DRF)*NN(I)
      AKP=AKP+CLW(I)*AXS(I)*GPJ*NN(I)
      UP1P=UP1P+UPW*AXS(I)*DENUP
      UP2P=UP2P-UPW*AXS(I)*C4*CCHOUT(I)
      UPW=CMPLX(0.,0.)
      UP3P=UP3P+UPW*AXS(I)*GPJ*NN(I)
      PUP1(I)=UP1P*CXJ1(I)+UP2P*CXA1(I)
      PUP3=PUP3+(UP1P*CXJ3(I)+UP2P*CXA3(I))*NN(I)
      PUP4=PUP4+(UP1P*CXJ4(I)+UP2P*CXA4(I)+UPW*PJOUT(I)*AXS(I)*DRF)
     @     *NN(I)
      DO 80 J=1,NP1
      PUP2(I,J)=UP1P*CXJ2(I,J)+UP2P*CXA2(I,J)
   80 CONTINUE
C QQQQGQQQQQQQQQQQQQQQQQQQQQQQQQuQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
   12 CONTINUE
      UP3P=1./GC*(AJUP*UPJ3+AAUP*CL12+APUP)+UP3P
      PUP4=PUP4+UP3P
      BP=BP+UPJ3
      AKP=AKP+CL12
C     A4P=AJUP*RJ3P+AAUP*F3P+APUP
C
C    2) FOR THE RISER
C
      DELR = RL - RP2
      RPI1=CHOMO1
      RPI2=CHOMO2
      SUP5 = -S*CLT
      SUPT = CEXP(SUP5)
C
      RX1 = ( (S/GC + CL1)*CL2 + CL3 )*DELR + (RKIN+RKEXIT)*CR5
      CR1 = -S*DELR/CKRO
      CR2 = C4*CKRO/S
      RX2 = (CR2*CKRO*(S/GC+CL1)+(CL5+CL6)/GC+CL4/S+CR2*G1/GC)
     1          * (CEXP(CR1) - 1.) + (RKIN+RKEXIT*CEXP(CR1))*CR6
      RT1 = RO11*RX1 + RO21*RX2
      RT2 = RO12*RX1 + RO22*RX2
      DO 10 I=JLL,JRR
      SUP1(I) = RJ1(I)*RT1 + F1(I)*RT2*SUPT
      SUP2(I) = RJ2(I)*RT1 + F2(I)*RT2*SUPT
      SUP3(I) = RJ3(I)*RT1 + F3(I)*RT2*SUPT
   10 CONTINUE
      RR2 = CMPLX(0.,0.)
      RR3 = CMPLX(0.,0.)
      RR4=CMPLX(0.,0.)
      DO 11 I=JLL,JRR
      RR1(I) = (SUP1(I)*CXJ1(I) + SUP2(I)*CXA1(I))/AXS(I)/DENSF +
     1          SUP3(I)
      RR2 = RR2 + (SUP1(I)*HUB1(I) + SUP2(I)*HUB2(I))
      RR3 = RR3 + (SUP1(I)*CXJ3(I) + SUP2(I)*CXA3(I))
   11 CONTINUE
C
      VOLR=0.
      DGDPR=S/HFG1*(1./PJ-DENSF*(1.-ALPRO)*DHF1(P)-RHOG*ALPRO
     @ *DHG1(P))
      C1R=VFG1*DGDPR-ALPRO/RHOG*S*DRHOG-(1.-ALPRO)/DENSF*S*DRF
      IF(RPO .LE. .00001)GO TO 5
      VOLR=AP*DPR-PI/3.*DPR**3+(PI*RPO-AP/RPO)*DPR**2/2.
    5 C2R=DGDPR/RHOG-ALPRO/RHOG*S*DRHOG-ALPRO*COR*C1R
      REP=CEXP(-S*ZLR/CKRO)
      GP=DDR*ALPRO*CKRO-C4*ALPRO*(DCOR*VRO+DVGJR)+DRF*VRO
      VGJP=VGJR+(COR-1.)*VRO
      V1BP=DENSF*RHOG*VGJP**2/(ROR**2-RHOG*ROR)**2*(2.*DENSF*ROR
     @     -ROR**2-DENSF*RHOG)
      V2BP=(DENSF-ROR)/(ROR-RHOG)*DENSF*RHOG/ROR*VGJP
      V3P=2.*V2BP*C1R*ZLR+V1BP*C4*C2R/S*(1.-REP)
      ROP=DENSF-C4*COR*ALPRO
      DELG=-C4*VGJR*ALPRO
      IF(IPILO .EQ. 0) GO TO 13
      RPI1 = DD1*XROUT**(-0.176)/(VFG1*DENSF)
      RPI2 = 1.
      GO TO 14
```

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 13 RPI1 = CHOMO1
    RPI2 = CHOMO2
 14 CORPR = RPI2 + RPI1*VFG1*DENSF*XROUT
    EV=2.*GOR*CORPR/DENSF-RPI1*VRO
    PCR4=ROP*EV/2.+GOR*RPI1/2.
    PCR5=-C4*CKRO*EV/2.
    PCR6=GP*EV/2.+GOR/2.*RPI1*VRO*DRF/DENSF
    GPS=ROP*C1R*ZLR-C4*CKRO*C2R/S*(1.-REP)+GP
    CR6S=GPS*EV/2.+GOR/2.*RPI1*VRO*DRF/DENSF
    UPREP=CEXP(-S*VOLR/(UPJIN*AP))
    AJRP=(S*ROP+FRR*GOR/DR*CORPR*ROP/DENSF+FRR*RPI1/2./DR
   @       *DELG)*ZLR+(RKIN+RKEXIT)*PCR4
    AARP=(REP-1.)*(CKRO*C4/S*(G1+FRR*CKRO/2./DR*EV)+C4*(V1BP
   @       +(GOR/ROR)**2-2.*GOR*CKRO/ROR))
   @       +(RKIN+RKEXIT*REP)*PCR5
    VR2=(GOR/ROR)**2-2.*GOR*CKRO/ROR
    APRP=(G1+FRR*CKRO/2./DR*EV+S/CKRO*VR2+S*CKRO)
   @       *C4*C2R*CKRO/S**2*(1.-REP)+V1BP*C4*C2R/S*(1.-REP)
   @  +(S+FRR/2./DR*EV)*(GP-C4*CKRO*C2R/S+ROP*C1R*ZLR/2.)*ZLR
   @       +G1*ZLR*(-C4*C2R/S+DRF+ALPRO*DDR)+2.*GOR*C1R*ZLR
   @       *ROP/ROR+2.*V2BP*C1R*ZLR+RPI1*FRR*GOR**2*ZLR/2./DR
   @       /DENSF*(DENSF*C1R*ZLR/2./GOR+VRO/GOR*DRF)
   @       +RKIN*PCR6+RKEXIT*CR6S
    G1R=ROP
    G2R=-C4*CKRO
    GPR=GP
    G1P=DENSF-C4*UPALP
    G2P=-C4*UPJIN
    GPP=DDR*UPALP*UPJIN+DRF*UPJIN
    F1RP=-DENSF*RHOG*ALPRO*VGJR/GOR**2
    F2RP=(COR*RHOG/DENSF+RHOG*VGJR/GOR+XROUT*COR*C4/DENSF
   @       +ALPRO*RHOG*C4*VGJR*CKRO/GOR**2)/(ROP/DENSF)
    F3RP=-(ALPRO*DRHOG*(COR/DENSF*(XROUT-1.)-VGJR/GOR*
   @       (1.-RHOG*ALPRO*CKRO/GOR))-ALPRO/DENSF*DCOR*
   @       (RHOG+XROUT*ALPRO*C4+DENSF*RHOG*VGJR*C4*
   @       VRO*ALPRO/GOR**2)-ALPRO*RHOG/GOR*DVGJR*
   @       (1.+VGJR*ALPRO*C4/GOR)-ALPRO*COR/DENSF*DRF*
   @       (XROUT-RHOG/DENSF))/(ROP/DENSF)
    F1PP=0.
    F2PP=(RHOG+XROUT*C4)/G1P
    F3PP=-(UPALP*DRHOG*(XROUT-1.)-UPALP*DRF*(XROUT-RHOG/DENSF))/
   @        G1P
    DELTA=F1RP*G2R-F2RP*G1R
    XJ1RP=(G2R*F1PP-G1P*F2RP)/DELTA
    XJ2RP=(G2R*F2PP-G2P*F2RP)/DELTA
    XJ3RP=(G2R*(F3PP-F3RP)-(GPP-GPR)*F2RP)/DELTA
    XJ1R=XJ1RP*AP/RAR
    XJ2R=XJ2RP*UPREP
    XJ3R=XJ1RP*VOLR/RAR*C1UP+XJ2RP*C2UP/S*(1.-UPREP)+XJ3RP
    XK1RP=(-G1R*F1PP+G1P*F1RP)/DELTA
    XK2RP=(-G1R*F2PP+G2P*F1RP)/DELTA
    XK3RP=(-G1R*(F3PP-F3RP)+(GPP-GPR)*F1RP)/DELTA
    XK1R=XK1RP*AP/RAR
    XK2R=XK2RP*UPREP
    XK3R=XK1RP*VOLR/RAR*C1UP+XK2RP*C2UP/S*(1.-UPREP)+XK3RP
    XJ1RS=XJ1R
    XJ2RS=XJ2R*UPEP
    XJ3RS=XJ1R*C1UP*ZLUP+XJ2R*C2UP/S*(1.-UPEP)+XJ3R
    XK1RS=XK1R
    XK2RS=XK2R*UPEP
```

```
      XK3RS=XK1R*C1UP*ZLUP+XK2R*C2UP/S*(1.-UPEP)+XK3R
      AJRPP=AJRP*XJ1R+AARP*XK1R
      AARPP=AJRP*XJ2R+AARP*XK2R
      APRPP=AJRP*XJ3R+AARP*XK3R+APRP
      AJR=AJRPP
      AAR=AARPP*UPEP
      APR=APRPP+AJRPP*C1UP*ZLUP+AARPP*C2UP/S*(1.-UPEP)
      PR3=CMPLX(0.,0.)
      PR4=CMPLX(0.,0.)
      DO 24 I=JLL,JRR
      NP1=NTOT(I)
      R3P=1./GC*(AJR*UPJW(I)+AAR*CLW(I))
      R1P=1./GC*(AJR*UPJ1(I)+AAR*CL11(I))+R3P*DENSF*AXS(I)
      R2P=1./GC*(AJR*UPJ2(I)+AAR*CL10(I))
      R4P=1./GC*(AJR*UPJ3+AAR*CL12+APR)
      PR1(I)=R1P*CXJ1(I)+R2P*CXA1(I)
      PR3=PR3+(R1P*CXJ3(I)+R2P*CXA3(I))*NN(I)
      PR4=PR4+(R1P*CXJ4(I)+R2P*CXA4(I)+R3P*PJOUT(I)*AXS(I)*DRF)*NN(I)
      DO 82 J=1,NP1
      PR2(I,J)=R1P*CXJ2(I,J)+R2P*CXA2(I,J)
   82 CONTINUE
   24 CONTINUE
      PR4=PR4+R4P
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
C     * PRESSURE DROP PERTURBATION BY THE DOWNCOMER LENGTH PERTURBATION
C
      CX10 = CMPLX(0.,0.)
      CX11 = CMPLX(0.,0.)
      CX13=CMPLX(0.,0.)
      XHG=HF(P)+HFG(P)
      AD1P=AD1
      WTURB=XROUT*WO
      XMS=RHOG*VDOME
      XMW=AD1*ZL1*DENSI
      VOL=VDOME+AD1*ZL1
      WC2P=S/HFG1*(XMS*DRHOG+XMW*DHF1(P)-VOL/PJ)
      DO 31 I=JLL,JRR
      NP1=NTOT(I)
      SH5=(FDL*DENSF*VIN(I)**2/(2*GC*DHDL)
     1     -G1/GC*DENSF)/(S*AD*DENSF)
      SPY=DRHOG/C4+RHOG/C4**2*DDR+VRO/(VFG1**2*GOR)*DVFGDP(P)
      ALPHA1=ROP
      ALPHA2=-C4*CKRO
      ALPHA3=GP
      ALPHA4=WIN*VRO/(VFG1*GOR**2)+(1.-XROUT)*RAR
      CX9=ALPHA1*ALPHA4-WIN/(VFG1*GOR)
      CX10=ALPHA2*ALPHA4
      CX11=ALPHA3*ALPHA4-WIN*SPY
      M=0
   99 M=M+1
      IF(M .GT. 4)GO TO 100
      PCL1=CX9
      PCL2=CX10*REP
      PCL3=CX9*C1R*ZLR+CX10*C2R/S*(1.-REP)+CX11
      SH1=PCL1*XJ1RS+PCL2*XK1RS
      SH2=PCL1*XJ2RS+PCL2*XK2RS
      SH3=PCL1*XJ3RS+PCL2*XK3RS+PCL3
      IF(M .EQ. 1)GO TO 91
      IF(M .EQ. 2)GO TO 92
      IF(M .EQ. 3)GO TO 93
      IF(M .EQ. 4)GO TO 94
   91 DWSW1(I)=SH5*(SH1*BJ(I)+SH2*AKJ(I))
      SW1(I)=DWSW1(I)/SH5
      DO 58 II=1,NP1
      DWSW2(I,II)=SH5*(SH1*BQ(I,II)+SH2*AKQ(I,II))
      SW2(I,II)=DWSW2(I,II)/SH5
   58 CONTINUE
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      DWSW3=SH5*(SH1*BH+SH2*AKH)
      SW3=DWSW3/SH5
      DWSW4=SH5*(SH1*BP+SH2*AKP+SH3-ZL1*AD*S*DRF+WC2P)
      SW4=DWSW4/SH5
      DWSW5=-SH5+S*SLOOP/GC+WO*SFLOOP/(DENSI*GC)-AA
      CX9=RAR*ALPHA1
      CX10=RAR*ALPHA2
      CX11=RAR*ALPHA3
      GO TO 99
   92 ST1(I)=SH1*BJ(I)+SH2*AKJ(I)
      DO 73 II=1,NP1
   73 ST2(I,II)=SH1*BQ(I,II)+SH2*AKQ(I,II)
      ST3=SH1*BH+SH2*AKH
      ST4=SH1*BP+SH2*AKP+SH3-ZL1*AD*S*DRF
      CX9=0.
      CX10=-C4
      CX11=ALPSEP*DRHOG
      GO TO 99
   93 SRHO1(I)=SH1*BJ(I)+SH2*AKJ(I)
      DO 75 II=1,NP1
   75 SRHO2(I,II)=SH1*BQ(I,II)+SH2*AKQ(I,II)
      SRHO3=SH1*BH+SH2*AKH
      SRHO4=SH1*BP+SH2*AKP+SH3-ZL1*AD*S*DRF
      CX9=1.
      CX10=0.
      CX11=0.
      GO TO 99
   94 SJ1(I)=SH1*BJ(I)+SH2*AKJ(I)
      DO 76 II=1,NP1
   76 SJ2(I,II)=SH1*BQ(I,II)+SH2*AKQ(I,II)
      SJ3=SH1*BH+SH2*AKH
      SJ4=SH1*BP+SH2*AKP+SH3-ZL1*AD*S*DRF
  100 CONTINUE
   31 CONTINUE
      SSWSW=XINER/GC
      SSWR=XKSEP*GOSEP/(GC*XRHOS*XASEP)
      SSRO=G1*XLSEP/GC-XKSEP*GOSEP**2
     @      /(2.*GC*XRHOS**2)
      DO 131 I=JLL,JRR
      NP1=NTOT(I)
      PR1(I)=PR1(I)+SSWSW*S*SW1(I)+SSWR*ST1(I)+SSRO*SRHO1(I)
      DO 133 J=1,NP1
      PR2(I,J)=PR2(I,J)+SSWSW*S*SW2(I,J)+SSWR*ST2(I,J)+SSRO
     @          *SRHO2(I,J)
  133 CONTINUE
  131 CONTINUE
      PR3=PR3+SSWSW*S*SW3+SSWR*ST3+SSRO*SRHO3
      PR4=PR4+SSWSW*S*SW4+SSWR*ST4+SSRO*SRHO4
      IF(ICAL .EQ. 3 .OR. ICAL .EQ. 5) GO TO 200
      GO TO 105
C
```

```
C     * CALCULATE THE INLET ENTHALPY PERTURBATION
C
  200 EPV = S*DENV*CPV/DKV
      EPV = CSQRT(EPV)
      WC1 = EPV*THV
      CC1 = DKV*EPV/(DKV*EPV + HOD/CCOTH(WC1))
      DPI = DENSI*ADC*S/WO + (PHV*HOD/WO/CPF)*CC1
      DTHET = -(CH5*PHV/WO) * (0.8*CC1-1.)
      DPIZ = -DPI*DLENG
      DPIE = CEXP(DPIZ)
      DBIZ = -CH3*DLENG
      DBIE = EXP(DBIZ)
      DDD = DTHET*(DBIE-DPIE)/(DPI-CH3)/WO + CH4*DPIE
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      DFE=ADC*S/(WO*PJ)
      EEE=(1-XROUT)*DPIE*DHF+DFE/DPI*(1-DPIE)
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
C     * FOR THE LOWER PLENUM
C
      WC2 = EPV*THLP
      CC2 = DKV*EPV/(DKV*EPV +HOLP/CCOTH(WC2))
      TLP1 = WO*DDD - CC2*AHLP*0.8*CH8/WO
      TLP2 = PLM*S + WO + CC2*HOLP*AHLP/CPF
      DPH1 = TLP1/TLP2
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      TLP=DPH1
      TLP4=(WO*EEE+PLM*S/(PJ*DENSI))/TLP2
  105 CONTINUE
 1000 CONTINUE
      RETURN
      END
C
C
C
C
C*****************************************************************
      SUBROUTINE DPPERT(S, XLAMB, IND, ICAL,IPP,IENT)
C*****************************************************************
C
C          CALCULATE FRESSURE DROP PERTURBATION IN THE CHANNEL
C
      INTEGER IOSUB
      REAL KI, KLOSS,KF
      COMPLEX S,M1,M2,M3,M4,TH1,TH2,TH3,GAM1,GAM2,GAM3,PI1,PI2,PI3
      COMPLEX STC1,STC2,CSTB1,CSTB2,Z3,HS,TG,TB1,TB2,TF,TR1,TR2,Z1,
     1        Z2,TALP1,TALP2,TALP3, TSUM2, TAU1,TAU2,PSUM
      COMPLEX CX1(30), CX2(30), CX3(30), CA(30), CB(30), CC(30),
     1        CXS2(30),CBS(30),MM4,SPA1,SPA2,SPA3, SPB1,SPB2,SPB3
      COMPLEX DP1,DP2,DP3,DP4,DP5,DP6,DP7,SO3
      COMPLEX DP1V,DP2V,DP3V,DP4V,DP5V,DP6V,  DP1Q,DP2Q,DP3Q,DP4Q,
     1        DP5Q,DP6Q,  DP1H,DP2H,DP3H,DP4H,DP5H,DP6H
      COMPLEX VAR1,VAR3,VAR4,VAR5,VAR6,Y3,Y4,B1,B2,B3,PAR1(30),
     1        PAR2(30),PAR3(30),CX,VV1,VV2,GT2V, GT2Q, GT2H
      COMPLEX PINOD1(30),PINOD2(30,30),PINOD3(30),CKI1(30),CKI21(30)
     1        ,CKI22(30,30),CKI3(30),SPK1(30),SPK2(30,30),SPK3(30)
      COMPLEX SUMP1, SUMP2(30), SUMP3, SPT1, SPT2(30), SPT3
      COMPLEX PP1V, PP1H,PP2V,PP2H,PP3V,PP3H,PP4V,PP4H,PP5V,PP5H
C
      COMPLEX RX1, CR1, CR2, RX2, RR1, RR2(30), RR3, T1, SUPT
      COMPLEX CC7, SUP1, SUP2, SUP3, SH1, SH2, SH3, SH4, SH5, DPHI
      COMPLEX ALSUM, FPV(30), F11, SUM2(30)
      COMPLEX EPV, WC1, WC2, CC1, CC2, CC4, DP1, DTHET, DP1Z, DP1E,
     1        DDD, TLP1, TLP2, CCOTH, DWSW1, DWSW21, DWSW2(30),
     2        DWSW3, UPC1, UPC2
      COMPLEX SC1,SC2,SC3,SC4,SC5,SC7,SC8,SC9,SC10,SC11,SC12,SC13,
     1        SC14,SC15,SC16,   SIN1,SIN2,SIN3,SIN4,SIN5,SIN6,SIN7,
     2        SIN9,SIN10,SIN11, SCO1,SCO2,SCO3, EPOW,GIFN1,GIFN2,
     3        AO1,AO4,AO5,  U1K,U2K,U3K,U4K,U5K
      COMPLEX WK(6,30),YOK,YK(8,30),SUMS,SUMS1,SUMS2,SUMS3,SUMS4,
     1        ZLK(7,30,30), SB1X,SB2X(30),SB7X,SBX(7,30),SK11(30),
     2        SK12(30,30),SK13(30), SBZK(7,30,30), SBTK(6,30,30),
     3        SGAM(30,30), SBM1(30),SBM2(30,30),SBM3(30), SBJ1(30),
     4        SBJ3(30),SBJ2(30,30),SBJ21(30), CSM1,CSM2,CSM3,
     5        SBM21(30), CXJ1,CXJ2,CXJ3,CXA1,CXA2,CXA3,SBTO,SBF
C
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMPLEX CXJ4,CXA4,TCP,TLOOP4,VPL,TH4,SUM2Y,XSB7(30)
      COMPLEX  SG1,SG21,SG3,SG22,SG4,SUMS3P,FF,CS,CSBEX
      COMPLEX VJ1,VJ21,VJ22,VJ3,VJ4
      COMPLEX BM1,BM21,BM22,BM3,BM4,AK1,AK21,AK22,AK3,AK4
      COMPLEX PM4,GAM4,CLTX,EDP1,EDP2,EDP3,CSB9PP,TLP,DWSW4
      COMPLEX SPT4,SPK4(30),CK141(30),CK142(30),B4,PP,PAR4(30),
     1        SPA4,SPB4,SUMP4,PINOD4(30),TALP4,PP6,PAR4P,
     2        VAR4P,GT2P,PP1P,DP1P,DP2P,DP3P,DP4P,DP5P,DP6P,DP7P,
     3        DP8P,DP9P,DP10P,DP11P,DP12P,DP13P,DP14P,DP15P,
     4        STC3,STC4,STC5,STC6,
     5        CD(30),CX4(30),P14,SUM7P,DP16P,DP17P
      COMPLEX PP3,SUP3P,RX3,RO14,RO24,CLP1,CLP2,CLP3,CLP4,CLP5,CLP6,
     1        CLP7,CLP8,WP1,WP2,WP3,CRP1,CRP2,CRP3,CRP4,CRP6,CRP7,
     2        CRP9,CRP10,ROA,ROB,RR4,DGAMP
      COMPLEX DPUP4,TLP4,DWSW4P,SH6,EEE,DFE,AUP1,UPP1
      COMPLEX SBJ4(30),SBM4(30),SUMS5P,SUMS4P,SBZP(30),
     1        SUM3P,SUM4P,U6K,SC17,SC18,SC19,SC20,SC21,
     2        SC22,AO6,AO7,SINO,SIN13,SIN12,
     3        SC3P1,SC3P21,SC3P2,SC3P,SK14(30)
      COMPLEX PPS,PPSP,OMH,PC4,CK142S,SK14S,CW,CW2,OMEGA
     @        ,STOM,STOM2,CSBX3,ZP,AJUP,AAUP,APUP,UPEP,C1UP
     @        ,C2UP,DGDP,UP1P,UP2P,UP3P,A2A,ST2V,ST21,PSJ4
      COMPLEX YF,YA1,YA2,YA3,YA4,YA5,YA6,YB1,YB2,YB3,YB4,YB5,YB6,
     @        YY0,YY1,YY2,YY3,YY5,YY6,YC11,YC12,YC13,YC14,YC21,
     @        YC22,YC23,YC31,YC32,YC33,YC34,YC41,BF1,BF2,BF3,BF4,
     @        BF1A,BF2A,BF3A,BF4A,VVJ,VVK,VVW,ZC1,ZC2,ZC3,ZHK,VKP
      COMPLEX YUS1(30),YUS2(30),YUS3(30),YUS5(30),YUS6(30),YUS4(30)
      COMPLEX YJS(6),YKS(6),YR(6),YG(30,6),YP(30,6),YGP(6),
     @        YGPIN(6),YGPOT(6),YSIN(6),YSOT(6),YGS(6),YPS(6),
     @        YRS(6),YD(6),YC(6),H2KP,Y9D,SUM2Z,CAUX
      COMPLEX U1KD,U2KD,U3KD,U4KD,U5KD,U6KD,WH,WP,AAA,ZF,PSBG,XLAM4
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      NAMELIST/THP/TH1,TH2,TH3,TH4
      DIMENSION SG22(30),BM22(30),AK22(30),VJ22(30)
      COMMON/OPTION/ IOSUB, IOHW, IO2Q, IPILO, ISLIP, IRW
      COMMON/CONST1/ C1(5),C2(5),C3(5),C4,C5(5),C8(5,30),
     1        C9(5,30),C18(5), C21(5), C22(5),C25(5),
     2        C26(5), I6, V7(5), DD1, CK1, CMP
      COMMON /CONSUB/ CSB2(5,30),CSB3(5,30),CSB4(5,30),
     1        CSB5(5,30),CSB6(5,30),CSB7(5,30),CSB8(5,30),
     2        CSB9(5,30),CSB10(5,30),CSBQ(5,30),CSBD(5,30),
     3        CSBE(5,30),CSBF(5,30), CSBG(5,30),CSBX1(5),
     4        CSBX2(5)
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```
      COMMON/CONSI2/ P,VCH,VIN(5),AXS(5),DH(5),DHIN(5),
     1       PH(5),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2       DENSF,VFG1,RHOG,GO(5),GO2(5),HO(5),GC,G1,KLOSS(30),
     3       FRICMO(5),VGJH(5,30),COH(5,30),CZERO,VGJ,DPTS,
     4       GO2RF(5),HFG1,ZSP(30),NUMBSP(5,30),ALHEAT,CXF(5),
     5       AVEQ,CHOMO1,CHOMO2,XKIN(5),XKEXIT(5)
C
      COMMON/CONSS1/ QDIS(5,30),QO(5,30),DZ(5,30),Z(5,30),
     1       K1(5,30), CKIN(5,30), ZETA(5,30), DOIN(5,30),
     2       DOOUT(5,30),ALPIN(5,30), BEE(5,30),CPI1(5,30),
     3       COR2PH(5,30), ZETSP(5,30), WIN
      COMMON /DIM1/ DELX, DELZ, CHLAMB(5), ALFNOD(5,30),
     1        BBLAMB(5)
      COMMON /DPCON1/GAM1(5),GAM2(5,30),GAM3(5), PI1(5),
     1               PI2(5,30),PI3(5), TALP1(5,30),
     2               TSUM2(5,30),TAU1(5),TAU2(5),TALP3(5,30)
      COMMON /WD2/Z1, Z2, Z3(30)
      COMMON/CONSS2/ NTOT(5),NBB(5),NBB1(5),NSP,N1PSP(5),
     1              K2PSP(5), NDP(5), NDP1(5), ISUB(5)
      COMMON /CPBOIL/ M1, M2, M3, TH1,TH2,TH3, HS(30),PM4,TH4
      COMMON /PBOIL/ CONBB
      COMMON /DPCON3/ ST2(30)
      COMMON /DPCON2/ STC1(30), STC(5,30), CSTB1(30), CSTB2(30),
     1                STC2(30)
      COMMON /CMP2/TG(11,30),TB1(4,30),TB2(4,30),TF(19,30),
     1       TR1(12,30),TR2(12,30)
      COMMON /CXCH/ CXJ1(5),CXJ2(5,30),CXJ3(5), CXA1(5),
     1              CXA2(5,30),CXA3(5)
      COMMON /CGHT/ F11
      COMMON /RESULT/XZ, SS1, SS2
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMMON/COREP/ STC3(30),STC4(30),STC5(30),STC6(30),PP(30),
     1              TALP2(5,30,30),TALP4(5,30),TLP4,PJ
      COMMON/DELTAP/DGAMP,DRHOG,DHF,DHG,DCZERO,DVGJ,DCOR,DVGJR
      COMMON/RISERP/CLTX,RR4,CRP5,CRP8,RO13,RO23,CL12,UPJ3,ALPRO,
     1              GOR,RHOR,VRO,CRCON,UPALP
      COMMON/SUBP/YSTAR(5,30),ENHTP
      COMMON/SUBPP/PVGH(5,30)
      COMMON/STABP/ TLP,DWSW4
      COMMON/PCON2P/PPS(30)
      COMMON/PPQQ/GAM4(5),PI4(5)
      COMMON/PSP/CSBX3(5,30),ALOUT(5,30)
      COMMON/PXX/PXEXT(5,30)
      COMMON/PWD/ZP(30)
      COMMON/YYY/ZLUP,FLUP,GOU,DHUP,ROUP,FUP,ZLR,FLR,ROR,FRR
     @          ,ADLP,DHLP,ZLLP,FLLP,XKLP,GOLP,FLP
     @          ,AD1,DH1,ZL1,FL1,XK1,GO1,FD1
     @          ,AD2,DH2,ZL2,FL2,XK2,GOD2,FD2
     @          ,AD3,DH3,ZL3,FL3,XK3,GO3,FD3
     @          ,SPUMP,CPUMP
      COMMON/PGAM/IGAM,IDRF
      COMMON/PCXCH/CXJ4(5),CXA4(5)
      COMMON/YCYS/TCS
      COMMON/KEY/THO,IKEY
      COMMON/HLDY/SH1,SH2,SH3,SH4
      COMMON/CFSUB/CF(5,30),CG(5,30)
      COMMON/HLDZ/H2KP(30)
      COMMON/SBHP/B4K(5,30),B5K(5,30),BTEMO(5,30),AVGX(5,30)
C   QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      DRF=DRFDP(P)
      IF(IDRF .EQ. 0)DRF=0.
      DDR=DRGDP(P)-DRF
      DRGFP=DRGDP(P)-RHOG/DENSF*DRF
C
       CHD1 = CSBX1(IND)
       CHD2 = CSBX2(IND)
      NP1 = NTOT(IND)
      NOSB = ISUB(IND)
      IF(NOSB .EQ. 0) NSF = NDP(IND)
      NTS = NDP1(IND)
      NIN=NTS
        IF(IOSUB .EQ. 0) GO TO 6678
        IF(NOSB .GT. 0) GO TO 10
      M4 = CONBB*SH2
      GO TO 9
   10 M1 = CMPLX(0.,0.)
      M2 = CMPLX(0.,0.)
      M3 = CMPLX(0.,0.)
      M4 = CMPLX(0.,0.)
      PM4=CMPLX(0.,0.)
    9 NFB1 = NBB(IND)
      NFB2 = NBB1(IND)
 6678 NSP1 = NTS + 1
C
C
      GAM1(IND) = CMPLX(0.,0.)
      GAM3(IND) = CMPLX(0.,0.)
      GAM4(IND)=CMPLX(0.,0.)
      DO 7 I=1,NP1
      SBM3(I) = CMPLX(0.,0.)
      GAM2(IND,I) = CMPLX(0.,0.)
    7 CONTINUE
      DO 3806 I=1,NP1
      DO 3806 J=1,NP1
      PINOD2(I,J) = CMPLX(0.,0.)
      SPK2(I,J) = CMPLX(0.,0.)
      TALP2(IND,I,J) = CMPLX(0.,0.)
 3806 CONTINUE
C.......................................................................
C     * CALCULATE SINGLE-PHASE PRESSURE DROP PERTURBATION
C.......................................................................
      IF(NOSB .GT. 0) GO TO 617
      OH = 0.
      NSPAC = NIPSP(IND)
      IF(NSPAC .EQ. 0) GO TO 641
      DO 6 I=1,NSPAC
      OH = OH + KLOSS(I)*GO(IND)/GC
    6 CONTINUE
  641 OH = OH + XKIN(IND)*GO(IND)/GC
      GAM1(IND) = (DENSF*S/GC + C3(IND))*XLAMB + OH + C2(IND)*M1
      DO 8 I=1,NSF
      CAUX=M2
      IF(IOSUB .NE. 0 )CAUX=M2*(1.+SH2/(CPF*Z2))
      GAM2(IND,I) = C2(IND)*CAUX*HS(I)
    8 CONTINUE
      GAM2(IND,NTS) = C2(IND)*M4
      GAM3(IND) = C2(IND)*M3
      GAM4(IND)=C2(IND)*PM4
      GO TO 200
  617 GAM1(IND) = XKIN(IND)*GO(IND)/GC
```

```
C............................................................
C     * CALCULATE THE PRESSURE DROP PERTURBATION IN THE TWO-PHASE
C                REGION
C............................................................
   200 DO 20 I=NTS,NP1
      CZERO=COH(IND,I)
      CX = 1./ZETA(IND,I)**2 - 1./CSTB2(I)
      CX1(I) = -STC2(I)*COH(IND,I)*K1(IND,I)*CX
      CX2(I) = STC2(I)*CKIN(IND,I) * CX * C5(IND) * Z3(I)
        CXS2(I) = STC2(I)*CKIN(IND,I)*CX
      CX3(I) = 1./CSTB2(I)
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      ZZZ=ZETA(IND,I)
      CX4(I)=STC3(I)*(1-1/CSTB2(I))+
     1      STC4(I)*(1/ZETA(IND,I)-1/CSTB2(I))
     2      +STC5(I)*CX+STC6(I)*((ALOG(ZZZ)-1./(S/CZERO/K1(IND,I)-
     3      1.))/ZZZ**2+1./CSTB2(I)/(S/CZERO/K1(IND,I)-1.))
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      PAR1(I) = (STC2(I)*CKIN(IND,I)/DZ(IND,I)) * ((1./ZETA(IND,I)
     1         -1.) - (COH(IND,I)*K1(IND,I)/S)*(1./CSTB1(I)-1.) )
      PAR2(I) = (STC2(I)*CKIN(IND,I)**2/DZ(IND,I)) * ((1./CSTB1(I)
     1         -1.)/S - (1./ZETA(IND,I)-1.)/(COH(IND,I)*K1(IND,I)) )
      PAR3(I) = -(CKIN(IND,I)/DZ(IND,I)/S) * (1./CSTB1(I)-1.)
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C ADD PSI4 TO CODE
      A2A=-1.+S/(CZERO*K1(IND,I))
      PAR4P=CZERO*K1(IND,I)/S*(1/CSTB1(I)-1)
      PAR4(I)=CKIN(IND,I)/(DZ(IND,I)*CZERO*K1(IND,I))
     1        *(STC3(I)*((ZETA(IND,I)-1)+PAR4P)
     2         +STC4(I)*(ALOG(ZETA(IND,I))+PAR4P)
     3         +STC5(I)*(-(1/ZETA(IND,I)-1)+PAR4P)
     4         +STC6(I)*(-1/ZETA(IND,I)*ALOG(ZETA(IND,I))
     5         -(1/ZETA(IND,I)-1)))
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      PAR4(I)=PAR4(I)+STC6(I)*(-PAR4P/A2A+(1./ZZZ-1.)/A2A)*
     @ CKIN(IND,I)/(DZ(IND,I)*CZERO*K1(IND,I))
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
   20 CONTINUE
C
C
C    * TRANSFER FUNCTIONS FOR SUBCOOLED BOILING NODE EXIT ENTHALPY
C              PERTURBATION
C
      IF(IOSUB .EQ. 0) GO TO 401
       NSP1 = NTS + 1
      PE=GO(IND)*DH(IND)*CPF/KF
      SBX1=-.0022*DH(IND)*CPF/KF
      SBX2=0.
       IF(PE .GE. 7.0E+04)GO TO 77
       GO TO 79
   77 SBX1=-154./GO(IND)
   79 CONTINUE
      DO 201 K=NTS,NFB1
      IF(PE .GE. 7.0E+04)SBX2=154.*QO(IND,K)/GO2(IND)
       CZERO=COH(IND,K)
       VGJ=VGJH(IND,K)
      XJOUT=(CKIN(IND,K)*ZETA(IND,K)-VGJ)/CZERO
      XJOIN=(CKIN(IND,K)-VGJ)/CZERO
      XJAG=(XJOIN+XJOUT)/2.
       SC1 = 1. - STC1(K)
```

```
        SC2 = (EPOW(ZETA(IND,K),SC1)-1.)/SC1
         CO1 = CKIN(IND,K) / (COH(IND,K)*K1(IND,K)*DZ(IND,K))
         CO2 = CKIN(IND,K)/COH(IND,K)
         CO3 = VGJH(IND,K)/COH(IND,K)
         SCO1 = 2.-STC1(K)
         SCO2 = CO2*(EPOW(ZETA(IND,K),SCO1)-1.)/SCO1
         SCO3 = -CO3*SC2 + SCO2
        SC3=CO1 * (TG(1,K)*(CO2*(ZETA(IND,K)-1.)-CO3*ALOG(ZETA(IND,K)))
      1             + TG(2,K)*SCO3 )
        SC3 = (1.-SC3/GO(IND)) / (VFG1*GO(IND))
        SC4=CO1 * ((-CO3*TG(3,K)+CO2*TG(4,K))*(ZETA(IND,K)-1.) - CO3*
      1             TG(4,K)*ALOG(ZETA(IND,K)) + (CO2/2.)*TG(3,K)*
      2             (ZETA(IND,K)**2-1.) + TG(5,K)*SCO3)
        SC4 = (DZ(IND,K)/2.-SC4/GO(IND)) / (VFG1*GO(IND))
        SC5 = CO1 * SCO3 * TG(6,K)
        SC5 = -SC5/(VFG1*GO(IND)**2)
        SC7 = CSB5(IND,K)*S - CSB2(IND,K)
        SC8 = CSB8(IND,K)*SC3
        SC9 = CSB9(IND,K)*TG(1,K)
        SC10 = CSB9(IND,K)*TG(2,K)
        SC11 = CSB8(IND,K)*SC4 + CSB9(IND,K)*TG(3,K) + CSB7(IND,K)
        SC12 = CSB9(IND,K)*TG(4,K)
        SC13 = CSB9(IND,K)*TG(5,K)
        SC14 = CSB9(IND,K)*TG(6,K)
        SC15 = CSB5(IND,K)*S
        SC16 = CSB8(IND,K)*SC5
         IF(IENT .NE. 0)GO TO 750
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C    CALCULATE CONSTANT FOR SUBCOOLED BOILING MODEL
       SC3P1=PPS(K)/(VFG1*GO(IND))
       DP1 = (1.-S/(CZERO*K1(IND,K))) * ALOG(ZETA(IND,K))
       DP2 = CEXP(DP1) - 1.
       SC3P2=XJAG*CKIN(IND,K)/(VFG1
      1       *GO2(IND)*CZERO*K1(IND,K)*DZ(IND,K))
      2       *(TG(7,K)*(ZETA(IND,K)-1)+TG(8,K)/2*(ZETA(IND,K)**2
      3       -1)+TG(9,K)*ALOG(ZETA(IND,K))+TG(10,K)/(1-STC1(K))
      4       *DP2+TG(11,K)/2
      5       *(ALOG(ZETA(IND,K)))**2)
       SC3P3=DRGDP(P)/C4-RHOG/C4**2*DDR+XJAG/GO(IND)*DVFGDP(P)/
      @         VFG(P)**2
       OMH=QO(IND,K)*PH(IND)/AXS(IND)*DVFGDP(P)+
      @     VFG(P)*S/PJ-K1(IND,K)
      @     *DHG1(P)-C4/DENSF*ALFNOD(IND,K)*S*DHG1(P)
       SC3P=SC3P1-SC3P2-SC3P3
       SC17=CSB2(IND,K)/K1(IND,K)*OMH
       SC18=CSB9(IND,K)*GO(IND)*DVFGDP(P)/VFG1+CSB8(IND,K)*SC3P
      @      +CSB9(IND,K)*SC3P2*VFG1*GO(IND)**2/XJAG
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
        SIN1 = SC7*(1.-ZETA(IND,K))
        SIN2 = SC15*ZETA(IND,K)
        SIN3 = SC15*(1.-ZETA(IND,K))
        SIN4 = SC7*ZETA(IND,K)
        ETEST=CABS(SC7)
        IF(ETEST .GE. 170.)GO TO 95
        SIN5 = CEXP(SIN2) - CEXP(SC15)
        SIN6 = CEXP(SIN4) - CEXP(SC7)
        SIN7 = CMPLX(0.,0.)
        SIN9 = GIFN1(SIN7,-SC15,SIN3)
        SIN10 = GIFN1(SC1,-SC15,SIN3)
        SIN11 = CEXP(SIN4)
        GO TO 96
    95  CONTINUE
C
      XL=BTEMO(IND,K)/(CZERO*K1(IND,K))
      BCL=B5K(IND,K)/XL/(BTEMO(IND,K)/CZERO)
      FG=BCL*(XJAG/GO(IND)-VFG1*(1.-AVGX(IND,K)))
      CO2P=CO2/K1(IND,K)
      EPF=EXP(DZ(IND,K)/XL)
      SIN5=(EPF-CEXP(SIN1))*CO2P/SC15
      FGP=XJAG/(VFG1*GO(IND)**2)
      SIN6=-(SC3-1./(VFG1*GO(IND)))/FGP
      SIN7=-(SC4-DZ(IND,K)/(2.*VFG1*GO(IND)))/FGP
      SIN9=SC5/FGP
   96 CONTINUE
      FF=VFG1*(-K1(IND,K)/HFG1/VFG1*(DHG-DHF)+S/HFG1*(1./PJ
     @   -DENSF*DHF)+ALFNOD(IND,K)*S/HFG1*(DENSF*DHF-RHOG*DRHOG))
     @   +K1(IND,K)/VFG1*DVFGDP(P)
      WK(1,K) = CEXP(SIN1)
      WK(2,K) = (CSB10(IND,K)/SC7) * (1.-CEXP(SIN1))
      IF(ETEST .GE. 170.)GO TO 97
      WK(3,K) = ((SC8/SC15)*SIN5+SC9*SIN9+SC10*SIN10) / SIN11
      WK(4,K) = ((-CSB6(IND,K)/SC7)*SIN6+(SC11/SC15)*SIN5+SC12*SIN9+
     1             SC13*SIN10) / SIN11
      WK(5,K) = (SC14*SIN10+(SC16/SC15)*SIN5)/SIN11
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      PC4=CEXP(SC7*(1.-ZETA(IND,K)))
      WK(6,K)=(SC17/SC7*SIN6+SC18*SIN5/SC15)/SIN11+WK(4,K)*FF
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      GO TO 98
   97 CONTINUE
      WK(3,K)=(BCL+FG*SIN6)*SIN5
      WK(4,K)=SIN5*(DZ(IND,K)/2.*BCL+FG*SIN7+BCL*XL)-CSB6(IND,K)
     @        /SC7*(1.-WK(1,K))
      WK(5,K)=SIN5*FG*SIN9
      WK(6,K)=SIN5*(BCL*PPS(K)+FG*SC3P2/FGP-BCL*GO(IND)*(1.-
     @        AVGX(IND,K))*DVFGDP(P)+SC17/SC7*(1.-WK(1,K)))
     @        +WK(4,K)*FF
C
   98 CONTINUE
      GO TO 760
  750 CONTINUE
      YETA=1.+(HF(P)-PVGH(IND,K))/HFG1
      HLG=HF(P)+HFG(P)-PVGH(IND,K)
      YBO=CZERO*K1(IND,K)/CKIN(IND,K)
      FF=1./(S*DENSF*(1.-ALFNOD(IND,K))-K1(IND,K)/VFG1
     @   +HLG*CSBF(IND,K)/VFG1)
      CS=1./FF/(GO(IND)*(1.-PXEXT(IND,K)))
      ACS=1.
      CS=ACS*CS
      ZZZ=ZETA(IND,K)
      A1=.04167/CPF
      HFLD=C4*PH(IND)*QO(IND,K)/(AXS(IND)*DENSF*CSBQ(IND,K))
      YAO=VFG1/(YETA*HFG1*YBO)
      ZC1=DENSF*(1.-CZERO*ALFNOD(IND,K))
      ZC2=-DENSF*(XJAG*CZERO+VGJ)
      ZC3=(XJAG*(1.-CZERO*ALFNOD(IND,K))-VGJ*ALFNOD(IND,K))*DRF
     @      -DENSF*(XJAG*ALFNOD(IND,K)*DCZERO+ALFNOD(IND,K)*DVGJ)
      ZHK=1./((1.-CEXP(-CS*DZ(IND,K)))*FF)
      YUS1(K)=CEXP(-CS*DZ(IND,K))
      YUS2(K)=(PH(IND)/AXS(IND)-HLG*CSBQ(IND,K)*CSBD(IND,K)/VFG1
     @        /QO(IND,K))/ZHK
      DHDZ=-YDO*CSB9(IND,K)*GO(IND)*EXP(CSB2(IND,K)*ZZZ)
      YUS3(K)=-ZC1*DHDZ/ZHK
      CSBEX=CSBE(IND,K)-CG(IND,K)*S*CXS2(K)
      YUS4(K)=-HLG*CSBEX/VFG1/ZHK
      YUS5(K)=(HLG*CSBG(IND,K)/VFG1-ZC2*DHDZ)/ZHK
      DHFG=DHG-DHF
      VKP=-CSBQ(IND,K)*YSTAR(IND,K)*(RHOG*(DHG-DHF)
     @     +HFG1*DRHOG+DENSF*DHF+(HF(P)-PVGH(IND,K))*DRF)
     @ +CSBQ(IND,K)*CSBD(IND,K)*(-DHF/HFLD+DRHOG/RHOG)
     @ -A1*ALFNOD(IND,K)*DHF+A1*ALFNOD(IND,K)*(HF(P)-PVGH(IND,K))
     @ *DVFGDP(P)/VFG1+S*VFG1/HFG1*(1./PJ-(1.-ALFNOD(IND,K))*DENSF
     @ *DHF-ALFNOD(IND,K)*RHOG*DHG)
      VKP=VKP/VFG1
      YUS6(K)=(S/PJ-K1(IND,K)/VFG1*DHG-HLG*VKP-RHOG*ALFNOD(IND,K)
     @         *S*DHG-ZC3*DHDZ)/ZHK
      WK(1,K)=YUS1(K)
      WK(2,K)=YUS2(K)
      WK(3,K)=YUS3(K)
      WK(4,K)=YUS4(K)
      WK(5,K)=YUS5(K)
      WK(6,K)=YUS6(K)
      U1K=(1.-WK(1,K))/CS/DZ(IND,K)
      ZF=ZHK*(1.-U1K)*FF
      U2K=WK(2,K)*ZF
      U3K=WK(3,K)*ZF
      U4K=WK(4,K)*ZF
      U5K=WK(5,K)*ZF
      U6K=WK(6,K)*ZF
  760 CONTINUE
C
      KM1 = K - 1
      DO 451 J=1,6
      DO 451 L=NTS,NFB1
       ZLK(J,K,L) = CMPLX(0.,0.)
  451 CONTINUE
       DO 203 JJ=1,6
        IF(JJ .EQ. 1) GO TO 204
        IF(K .EQ. NTS) GO TO 205
         DO 207 JS=NTS,KM1
          IF(JS .EQ. KM1) GO TO 206
          SUMS = CMPLX(1.,0.)
          JSP1 = JS+1
           DO 208 J=JSP1,KM1
            SUMS = SUMS * WK(1,J)
  208      CONTINUE
          ZLK(JJ,K,JS) = SUMS * WK(JJ,JS)
          GO TO 207
  206     ZLK(JJ,K,JS) = WK(JJ,JS)
  207    CONTINUE
         GO TO 203
C
  205    DO 210 JS=NTS,NFB1
          ZLK(JJ,K,JS) = CMPLX(0.,0.)
  210    CONTINUE
       GO TO 203
C
  204    CONTINUE
         IF(K .EQ. NTS) GO TO 211
```

```
            SUMS = CMPLX(1.,0.)
             DO 212 JS=NIS,KM1
              SUMS = SUMS * WK(1,JS)
  212        CONTINUE
            ZLK(1,K,1) = SUMS
            GO TO 203
  211       ZLK(1,K,1) = CMPLX(1.,0.)
  203 CONTINUE
        IF(IENT .NE. 0)GO TO 753
C
C
C      * TRANSFER FUNCTIONS FOR THE NODE-AVERAGED LIQUID ENTHALPY
C           PERTURBATION IN THE SUBCOOLED BOILING REGION
C
         A01 = CKIN(IND,K)/(DZ(IND,K)*COH(IND,K)*K1(IND,K)*SC7)
         B01 = CSB2(IND,K)*ZETA(IND,K)
         B02 = EXP(B01) - EXP(CSB2(IND,K))
         SIN7 = CMPLX(1.,0.)
         A04 = GIFN2(SIN7,CSB2(IND,K),ZETA(IND,K))
         A05 = GIFN2(SIC1(K),CSB2(IND,K),ZETA(IND,K))
        U1K = A01 * (1.-WK(1,K))
        U2K = -A01*WK(2,K) + CSB10(IND,K)/SC7
        IF(ETEST .GE. 170.)GO TO 156
        U3K = A01 * (-WK(3,K)+(SC8/CSB2(IND,K))*B02+SC9*A04+SC10*A05)
        U4K = A01 * (-WK(4,K)-CSB6(IND,K)*(1.-ZETA(IND,K))+B02*
     1              (SC11/CSB2(IND,K))+SC12*A04+SC13*A05)
        U5K = A01 * (-WK(5,K)+(SC16/CSB2(IND,K))*B02+SC14*A05)
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
        U6K=SC17/SC7+SC18*A01/CSB2(IND,K)*B02-A01*WK(6,K)
     @      +U4K*FF
        GO TO 158
  156 CONTINUE
        A01=-1./SIN1
        SIN5=A01*XL*(EPF-1.)
        U3K=(BCL+FG*SIN6)*SIN5-A01*WK(3,K)
        U4K=SIN5*(DZ(IND,K)/2.*BCL+FG*SIN7+BCL*XL)-CSB6(IND,K)
     @      /SC7-A01*WK(4,K)
        U5K=SIN5*FG*SIN9-A01*WK(5,K)
        U6K=SIN5*(BCL*PPS(K)+FG*SC3P2/FGP-BCL*G0(IND)*(1.-
     @      AVGX(IND,K))*DVFGDP(P)+SC17/SC7-A01*WK(6,K))
     @      +U4K*FF
  158 CONTINUE
        RHF=DENSF*DHF+(HF(P)-PVGH(IND,K))*DRF
        A1=.041667/CPF
        HFLD=C4*PH(IND)*Q0(IND,K)/(AXS(IND)*DENSF*CSBQ(IND,K))
        VKP=-CSBQ(IND,K)*YSTAR(IND,K)*(RHOG*(DHG-DHF)
     @      +HFG1*DRHOG+DENSF*DHF+(HF(P)-PVGH(IND,K))*DRF)
     @ +CSBQ(IND,K)*CSBD(IND,K)*(-DHF/HFLD+DHFG/HFG1+DRHOG/RHOG)
     @ -A1*ALFNOD(IND,K)*DHF-A1*ALFNOD(IND,K)*HFLD*(DHFG/HFG1
     @ -DVFGDP(P)/VFG1)
  753 CONTINUE
        XLAM1=1.
        XLAM2=DZ(IND,K)/2.
        XLAM4=PPS(K)
        CSBFX=CSBF(IND,K)
        PSBG=CSBG(IND,K)-CSBFX*U5K
        YOK=1.-CSBFX*U4K+CSBG(IND,K)*PAR2(K)
        IF(IENT .NE. 0)YOK=1.+PSBG*PAR2(K)-CSBFX*U3K*XLAM2
        YK(1,K)=CSBFX*SH1/YOK
        YK(2,K)=(CSBQ(IND,K)*CSBD(IND,K)/Q0(IND,K)+CSBFX*
     @           U2K)/YOK
      YK(3,K)=CSBFX*U1K/YOK
      YK(4,K)=(U3K*CSBFX*XLAM1-PSBG*PAR1(K))/YOK
      YK(5,K)=-PSBG*PAR3(K)/YOK
      YK(6,K)=CSBEX*SH2/YOK
      YK(7,K)=(CSBFX*(U6K+U3K*XLAM4)-PSBG*PAR4(K)+
     @           CSBEX*SH4+VKP)/YOK
      YK(8,K)=CSBEX*SH3/YOK
      IF(K .EQ. NTS)Y9D=U4K*CSBFX/YOK
C
C
      SB1X = YK(1,K)
      SB2X(K) = YK(3,K) * ZLK(1,K,1)
      IF(IENT .NE. 0)SB2X(K)=U4K*CSBF(IND,K)/YOK
      IF(IENT .NE. 0)GO TO 9908
      GO TO 9909
 9908 KM1=K-1
      IF(KM1 .EQ. 0)GO TO 9909
      DO 99 JJ=NIS,KM1
   99 SB2X(K)=SB2X(K)+YK(3,K)*ZLK(4,K,JJ)
 9909 CONTINUE
      SB7X = YK(6,K)
      XSB7(K)=YK(6,K)
       DO 213 J=3,7
        JM1 = J-1
       DO 213 JJ=NTS,K
        IF(JJ .EQ. K) GO TO 214
        SBX(J,JJ) = YK(3,K)*ZLK(JM1,K,JJ)
        IF(J .EQ. 5)SBX(J,JJ)=CMPLX(0.,0.)
        GO TO 213
  214   SBX(J,JJ) = YK(JM1,K)
        IF(J .EQ. 5) SBX(J,JJ)=CMPLX(0.,0.)
        IF(J .EQ. 4) SBX(J,JJ) = YK(J,K)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
       IF(J .EQ. 7) SBX(J,JJ)=YK(J,K)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
  213  CONTINUE
C
       SBZK(1,K,1) = SB1X + SBX(4,NTS)
        IF(NOSB .GT. 0) SBZK(1,K,1) = SB1X + SBX(4,NTS)
        IF(K .EQ. NTS) GO TO 876
       DO 299 J=NTS,KM1
  299  SBZK(4,K,J) = SBX(5,J)
  876  DO 215 J=NIS,K
        SBZK(2,K,J) = SBX(3,J)
  215  CONTINUE
       IF(K .EQ. NIS) GO TO 847
       DO 217 J=NSP1,K
        SBZK(3,K,J) = SBX(4,J)
        SBZK(5,K,J) = SBX(6,J)
  217  CONTINUE
  847 SBZK(6,K,1)=-(K1(IND,NTS)*SBX(4,NTS)+SBX(6,NTS)*
     @              C21(IND))
        IF(NOSB .GT. 0) SBZK(6,K,1) = CMPLX(0.,0.)
      DO 512 J=NIS,K
      SBZK(7,K,J)=SBX(7,J)
  512 CONTINUE
C
  201 CONTINUE
C
```

```
  401   NIR = NP1 +1
      IF(ICAL .EQ. 1 .OR. ICAL .EQ. 4) NIR = NP1
       IF(NOSB .GT. 0) CHD1 = 0.
       IF(NOSB .GT. 0) CHD2 = 0.
      K=NTS-1
  999 K=K+1
      IF(K .GT. NIR)GO TO 1000
      CZERO=COH(IND,K)
      VGJ=VGJH(IND,K)
      IF(K .EQ. NTS) GO TO 372
      DO 100 I=1,NP1
      CA(I) = CMPLX(0.,0.)
      CB(I) = CMPLX(0.,0.)
      CC(I) = CMPLX(0.,0.)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      CD(I)=CMPLX(0.,0.)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
  100 CONTINUE
C
C    * CLACULATE THE PARAMETERS FOR THE VOID-FRACTION PERTURBATION
C
      IF(IOSUB .NE. 0 .AND. K .GT. NFB2)NIN=NFB2
      VAR4 = CMPLX(1.,0.)
      KLOW = K - 1
      DO 25 I=NIN,KLOW
      IF(I .EQ. KLOW) GO TO 26
      VAR3 = CMPLX(1.,0.)
      JU = K - I - 1
      DO 27 J=1,JU
      JP = K - J
      VAR3 = VAR3*CX3(JP)
   27 CONTINUE
      CA(I) = VAR3 * CX1(I)
      CB(I) = VAR3 * CX2(I)
       CBS(I) = VAR3*CXS2(I)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      CD(I)=VAR3*CX4(I)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      GO TO 66
   26 CA(I) = CX1(KLOW)
      CB(I) = CX2(KLOW)
       CBS(I) = CXS2(I)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      CD(I)=CX4(KLOW)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
   66 VAR4 = VAR4 * CX3(I)
   25 CONTINUE
      CC(K)=VAR4
C
      VAR5 = CMPLX(0.,0.)
      DO 28 I=NTS,KLOW
   28 VAR5 = VAR5 + CA(I)
      CK11(K) = (1.-K1(IND,NTS)*M1)*VAR5 - C21(IND)*CC(K)*M1
      CAUX=M2
      IF(IOSUB .NE. 0 )CAUX=M2*(1.+SH2/(CPF*Z2))
      CK121(K) = -(VAR5 + CC(K)/(RHOG*CKIN(IND,NTS)*VFG1)) *
     1           K1(IND,NTS) * CAUX
      SK11(K) = VAR5
      DO 29 I=NTS,KLOW
      IF(I .EQ. NTS) GO TO 30
```

```fortran
      VAR6S=0.
      III = I + 1
      VAR6 = CMPLX(0.,0.)
      DO 31 J=III,K
   31 VAR6 = VAR6 + CA(J)
      CKI22(K,I) = VAR6*DZ(IND,I)*C5(IND)*Z3(I) + CB(I)
       SKI2(K,I) = VAR6*DZ(IND,I) + CBS(I)
      IF(I .EQ. KLOW)CKI22(K,I)=CB(I)
      IF(I .EQ. KLOW)SKI2(K,I)=CBS(I)
      GO TO 29
   30 CKI22(K,I) = CB(I)
       SKI2(K,I) = CBS(I)
   29 CONTINUE
      CKI3(K) = -(VAR5 + CC(K)/(RHOG*VFG1*CKIN(IND,NTS))) *
     1              K1(IND,NTS) * H3
       SKI3(K) = -VAR5*K1(IND,NTS) - CC(K)*C21(IND)
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      CKI41(K)=-(VAR5+CC(K)/(RHOG*VFG1*CKIN(IND,NTS)))*K1(IND,NTS)
     1           *PM4
      CKI42(K)=CMPLX(0.,0.)
      SKI4(K)=CMPLX(0.,0.)
      IF (K .EQ. NTS) GOTO 747
      DO 74 JJ=NIS,KLOW
      IF (JJ .EQ. NTS) GOTO 71
      KLOWP=JJ-1
      SUM7P=CMPLX(0.,0.)
      DO 73 JP1=NIS,KLOWP
      SUM7P=SUM7P+PP(JP1)
 73   CONTINUE
      CKI42(K)=CKI42(K)+CA(JJ)*SUM7P+CD(JJ)
      SKI4(K)=SKI4(K)+CA(JJ)*SUM7P+CD(JJ)
      GO TO 744
   71 CKI42(K)=CD(JJ)
      SKI4(K)=CD(JJ)
      SUM7P=CMPLX(0.,0.)
  744 IF(IOSUB .EQ. 0)GO TO 74
      IF(IOSUB .NE. 0 .AND. K .GT. NFB1)GO TO 74
   74 CONTINUE
  747 CONTINUE
      IF(IOSUB .NE. 0)GO TO 676
      GO TO 678
  676 CKI1(K)=CMPLX(0.,0.)
      CKI21(K)=CMPLX(0.,0.)
      CKI3(K)=CMPLX(0.,0.)
      CKI41(K)=CMPLX(0.,0.)
      CKI42(K)=CMPLX(0.,0.)
      DO 682 I=NTS,KLOW
      CKI22(K,I)=CMPLX(0.,0.)
  682 CONTINUE
  678 CONTINUE
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      IF(IOSUB .EQ. 0) GO TO 202
      IF(K .GE. NFB2 ) GO TO 225
      SUMS1 = CMPLX(0.,0.)
      SUMS2 = CMPLX(0.,0.)
      SUMS3=CMPLX(0.,0.)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      SUM3P = CMPLX(0.,0.)
      SUM4P=CMPLX(0.,0.)
      SUMS4=CMPLX(0.,0.)
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      DO 218 J=NSP1,K
       SUMS1 = SUMS1 + (SBZK(3,K,J) + SBZK(5,K,J)*SK11(J))
       SUMS2 = SUMS2 + (SBZK(3,K,J)*K1(IND,NTS) - SBZK(5,K,J)*
     1                  SK13(J))
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      JLOW=J-1
      SUM4P=CMPLX(0.,0.)
      DO 317 JJ=NTS,JLOW
       SUM4P=SUM4P+PP(JJ)
317   CONTINUE
      SUM3P=SUM3P+SBZK(3,K,J)*SUM4P+SBZK(5,K,J)
     1       *SK14(J)+SBZK(7,K,J)
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
  218 CONTINUE
      SBTK(1,K,1) = SBZK(1,K,1) + SUMS1
      SBTK(3,K,1) = SBZK(6,K,1) - SUMS2
      SBTK(5,K,1) = SB2X(K)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C  ADD 15,K TO SUBCOOLED BOILING MODEL
       SBTK(6,K,1)=SUM3P+SBZK(7,K,NTS)
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      DO 219 J=NTS,K
      SBTK(2,K,J) = SBZK(2,K,J)
  219 CONTINUE
      DO 220 J=NTS,KLOW
       SUMS3 = CMPLX(0.,0.)
       JP1 = J+1
       DO 221 JJ=JP1,K
        SUMS3 = SUMS3 + SBZK(3,K,JJ)*DZ(IND,J)+SK12(JJ,J)*SBZK(5,K,JJ)
  221  CONTINUE
      SBTK(4,K,J) = SUMS3 + SBZK(4,K,J)
  220 CONTINUE
C
C
  367 DO 222 J=NSP1,K
       IF(J .EQ. K) GO TO 223
        SUMS3 = CMPLX(0.,0.)
        DO 298 JJ=J,KLOW
         SUMS3 = SUMS3 + SBTK(4,K,JJ)*SGAM(JJ,J)
  298   CONTINUE
       SGAM(K,J) = SUMS3
        GO TO 222
  223  SGAM(K,J) = CMPLX(1.,0.)
  222 CONTINUE
C
C
      SUMS1 = CMPLX(0.,0.)
      SUMS2 = CMPLX(0.,0.)
      SUMS3 = CMPLX(0.,0.)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      SUMS4P=CMPLX(0.,0.)
      SUMS4=CMPLX(0.,0.)
      SUM2Y=CMPLX(0.,0.)
      SUM2Z=CMPLX(0.,0.)
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      DO 230 J=NSP1,K
       SUMS1 = SUMS1 + SGAM(K,J)*(SBTK(1,J,1) + SBTK(4,J,NTS)*
     1          (YK(1,NTS)+YK(4,NTS)))
```

```
         SUMS2 = SUMS2 + SGAM(K,J)*(SBTK(3,J,1) + SBTK(4,J,NTS)
     1        *(-K1(IND,NTS)*YK(4,NTS)
     2        - YK(5,NTS)*C21(IND)))
        SUMS3=SUMS3+SGAM(K,J)*(SBTK(5,J,1)+SBTK(4,J,NTS)*
     @        Y9D)
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
        SUMS4P=SUMS4P+SGAM(K,J)*(SBTK(4,J,NTS)*YK(7,NTS)
     1           +SBTK(6,J,1))
        SUM2Z=SUM2Z+SGAM(K,J)*XSB7(J)
        SUMS4=SUMS4+SGAM(K,J)*(SBTK(4,J,NTS)*YK(3,NTS)+
     @        YK(3,J)*ZLK(1,J,1))
        SUM2Y=SUM2Y+SGAM(K,J)*YK(8,J)
C   QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
  230 CONTINUE
        SBM1(K) = SUMS1 + SUMS2*M1 + SUMS3*SH1+SUMS4*SH1
        SBM21(K) = SUMS2*M2*(1.+SH2/(CPF*Z2))
     @             SUMS3*SH2*TH2/(CPF*Z2)
        SBM3(K) = SUMS2*M3 + SUMS3*SH3+ SUM2Y+SUMS4*SH3
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
        SBM4(K)=SUMS4P+SUMS2*PM4+SUMS3*SH4+SUMS4*SH4
C   QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
        DO 231 J=NTS,K
         IF(J .EQ. NTS) GO TO 232
          SUMS3P= CMPLX(0.,0.)
          DO 233 JJ=J,K
           SUMS3P= SUMS3P+ SGAM(K,JJ)*SBTK(2,JJ,J)
  233     CONTINUE
        SBM2(K,J) = SUMS3P* Z3(J)
        GO TO 331
  232 SUMS3P= CMPLX(0.,0.)
         DO 234 JJ=NSP1,K
          SUMS3P= SUMS3P+ SGAM(K,JJ)*(SBTK(2,JJ,NTS) + SBTK(4,JJ,NTS)*
     1              YK(2,NTS))
  234    CONTINUE
        SBM2(K,J) = SUMS3P*Z3(J) + SUMS3*SH2+M4*SUMS2+SUMS4*SH2
  331 SBM4(K)=SBM4(K)+SUMS3P*ZP(J)
  231 CONTINUE
        GO TO 228
C
  225 SBM1(K) = CMPLX(0.,0.)
        SBM21(K) = CMPLX(0.,0.)
        SBM3(K) = CMPLX(0.,0.)
        SBM4(K)=CMPLX(0.,0.)
         DO 226 JJ=NTS,K
         IF(K .EQ. NIR) GO TO 4829
         IF(JJ .EQ. K) GO TO 227
 4829     SBM2(K,JJ) = CMPLX(0.,0.)
          GO TO 226
  227     SBM2(K,JJ) = C5(IND)*Z3(JJ)
  226    CONTINUE
C
C      * TRANSFER FUNCTIONS FOR NODE INLET FLOW VELOCITY & VOID FRACTION
C                      PERTURBATION
C       SBJ1,21,2,3,4 ; T.F. FOR NODE INLET FLOW VELOCITY PERTURBATION
C       SBM1,21,2,3,4 ; T.F. FOR NODE CHARACTRISTIC FREQUENCY PERTURBATION
C       CK11,21,2,3,4 ; T.F. FOR NODE INLET VOID FRACTION PERUTRBATION
C
  228 SUMS1 = CMPLX(0.,0.)
        SUMS3 = CMPLX(0.,0.)
        SUMS4 = CMPLX(0.,0.)
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      PSUM=CMPLX(0.,0.)
      SUMS4P=CMPLX(0.,0.)
      IF(K .GE. NFB2 )GO TO 634
      DO 250 J=NTS,KLOW
       SUMS1 = SUMS1 + DZ(IND,J)*SBM1(J)
       SUMS3 = SUMS3 + DZ(IND,J)*SBM3(J)
       SUMS4 = SUMS4 + DZ(IND,J)*SBM21(J)
       SUMS2 = CMPLX(0.,0.)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      SUMS4P=SUMS4P+DZ(IND,J)*SBM4(J)+PP(J)
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
       DO 251 JJ=J,KLOW
        SUMS2 = SUMS2 + DZ(IND,JJ)*SBM2(JJ,J)
  251  CONTINUE
       SBJ2(K,J) = SUMS2
       IF(J .EQ. NTS) SBJ2(K,J) = SUMS2 - K1(IND,J)*M4
  250 CONTINUE
       SBJ1(K) = SUMS1 + 1. - K1(IND,NTS)*M1
       SBJ3(K) = -K1(IND,NTS)*M3 + SUMS3
       SBJ21(K) = -K1(IND,NTS)*M2*(1.+SH2/(CPF*Z2)) + SUMS4
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
       SBJ4(K)=SUMS4P-K1(IND,NTS)*PM4
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      SUMS1 = CMPLX(0.,0.)
      SUMS3 = CMPLX(0.,0.)
      SUMS4 = CMPLX(0.,0.)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      SUMS5P=CMPLX(0.,0.)
      SUMS4P=CMPLX(0.,0.)
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      DO 252 J=NTS,KLOW
       SUMS1 = SUMS1 + SK12(K,J)*SBM1(J)
       SUMS3 = SUMS3 + SK12(K,J)*SBM3(J)
       SUMS4 = SUMS4 + SK12(K,J)*SBK21(J)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      SUMS5P=SUMS5P+SK12(K,J)*SBM4(J)
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
       SUMS2 = CMPLX(0.,0.)
       DO 253 JJ=J,KLOW
        SUMS2 = SUMS2 + SK12(K,JJ)*SBM2(JJ,J)
  253  CONTINUE
       CK122(K,J) = SUMS2
       IF(J .EQ. NTS) CK122(K,J) = SUMS2 + SK13(K)*M4
  252 CONTINUE
      CK11(K) = SUMS1 + SK11(K) + SK13(K)*M1
      CK13(K) = SUMS3 + SK13(K)*M3
      CK121(K) = SUMS4 + SK13(K)*M2*(1.+SH2/(CPF*Z2))
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
       CK141(K)=SK13(K)*PM4
       CK142(K)=SUMS5P+SK14(K)
      IF(K .LT. NFB1)GO TO 255
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      DO 164 I=NTS,KLOW
      VJ22(I)=SBJ2(NFB1,I)
  164 AK22(I)=CK122(NFB1,I)
      VJ1=SBJ1(NFB1)
      VJ21=SBJ21(NFB1)
      VJ3=SBJ3(NFB1)
      VJ4=SBJ4(NFB1)
      AK1=CK11(NFB1)
      AK21=CK121(NFB1)
      AK3=CK13(NFB1)
      AK4=CK141(NFB1)+CK142(NFB1)
      GO TO 275
  634 SBJ1(K)=VJ1
      SBJ21(K)=VJ21
      SBJ3(K)=VJ3
      SBJ4(K)=VJ4
      KM1=K-1
      DO 655 JJ=NFB2,KM1
      SBJ4(K)=SBJ4(K)+PP(JJ)
  655 CONTINUE
      DO 625 II=NIS,KM1
      SBJ2(K,II)=DZ(IND,II)*C5(IND)*Z3(II)
      IF(II .LT. NFB1)SBJ2(K,II)=VJ22(II)
  625 CONTINUE
      CK11(K)=CC(K)*AK1
      CK121(K)=CC(K)*AK21
      CK13(K)=CC(K)*AK3
      CK141(K)=CMPLX(0.,0.)
      CK142(K)=CC(K)*AK4
      DO 865 JJ=NFB2,KM1
      CK11(K)=CK11(K)+CA(JJ)*SBJ1(JJ)
      CK121(K)=CK121(K)+CA(JJ)*SBJ21(JJ)
      CK13(K)=CK13(K)+CA(JJ)*SBJ3(JJ)
      CK142(K)=CK142(K)+CA(JJ)*SBJ4(JJ)+CD(JJ)
  865 CONTINUE
      KM2=KM1-1
      DO 574 JJ=NIS,KM1
      IF(JJ .LT. NFB1)GO TO 576
      IF(JJ .LE. KM2 .AND. JJ .GE. NFB2)GO TO 578
      CK122(K,JJ)=CB(JJ)
      GO TO 574
  578 III=JJ+1
      CK122(K,JJ)=CB(JJ)
      DO 580 II=III,KM1
      CK122(K,JJ)=CK122(K,JJ)+CA(II)*SBJ2(II,JJ)
  580 CONTINUE
      GO TO 574
  576 CK122(K,JJ)=CK122(NFB1,JJ)*CC(K)
      DO 572 II=NFB2,KM1
      CK122(K,JJ)=CK122(K,JJ)+CA(II)*SBJ2(II,JJ)
  572 CONTINUE
  574 CONTINUE
  275 SBM1(K) = CMPLX(0.,0.)
      SBM3(K) = CMPLX(0.,0.)
      SBM4(K)=CMPLX(0.,0.)
      SBM21(K)=CMPLX(0.,0.)
       DO 432 J=1,K
        SBM2(K,J) = CMPLX(0.,0.)
        IF(J .EQ. K) SBM2(K,J) = C5(IND)*Z3(J)
  432  CONTINUE
      GO TO 255
C
  202 SBJ1(K) = 1.- K1(IND,NIS)*M1
      SBJ3(K) = -K1(IND,NIS)*M3
      DO 254 J=NIS,KLOW
       SBJ2(K,J) = C5(IND)*DZ(IND,J)*Z3(J)
  254 CONTINUE
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```
      SBJ21(K) = -KI(IND,NTS)*M2
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      PSJ4=CMPLX(0.,0.)
      DO 256 J=NTS,KLOW
      PSJ4=PSJ4+PP(J)
  256 CONTINUE
      SBJ4(K)=PSJ4-KI(IND,NTS)*PM4
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      SBM1(K) = CMPLX(0.,0.)
      SBM3(K) = CMPLX(0.,0.)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      SBM4(K)=CMPLX(0.,0.)
      SBM21(K)=CMPLX(0.,0.)
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
       DO 402 J=1,K
        SBM2(K,J) = CMPLX(0.,0.)
        IF(J .EQ. K) SBM2(K,J) = C5(IND)*Z3(J)
  402  CONTINUE
      GO TO 255
C
C    * FOR THE BOUNDARY NODE WITH SUBCOOLED BOILING
C
  372 IF(IOSUB .EQ. 0) GO TO 378
       CSM1 = YK(1,K) + YK(4,K)
       CSM2 =  YK(2,K)
       CSM3 =-KI(IND,K)*YK(4,K)-C21(IND)*YK(5,K)
        SBM1(K) = CSM1+CSM3*M1+YK(3,K)*SH1+Y9D*SH1
        SBM21(K) = CSM3*M2*(1.+SH2/(CPF*Z2))+YK(3,K)*SH2+
     @             (YK(6,K)+Y9D*SH2)*(-TH2/(CPF*Z2))
        SBM2(K,K) = CSM2*Z3(K) + CSM3*M4+Y9D*SH2+YK(6,K)
        SBM3(K) = CSM3*M3+YK(3,K)*SH3+ YK(8,K)+Y9D*SH3
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
        SBM4(K)=YK(7,K)+CSM3*PM4+CSM2*ZP(K)+YK(3,K)*SH4+Y9D*SH4
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
       GO TO 379
C
C    * FOR THE BOUNDARY NODE WITHOUT SUBCOOLED BOILING
C
  378   SBM1(K) = CMPLX(0.,0.)
        SBM21(K) = CMPLX(0.,0.)
        SBM2(K,K) = C5(IND)*Z3(K)
        SBM3(K) = CMPLX(0.,0.)
        SBM4(K)=CMPLX(0.,0.)
C
  379   SBJ1(K) = 1.-KI(IND,K)*M1
        SBJ21(K) = -KI(IND,K)*M2
        SBJ2(K,K) = CMPLX(0.,0.)
         IF(IOSUB .EQ. 1) SBJ2(K,K) = -KI(IND,K)*M4
        SBJ3(K) = -KI(IND,K)*M3
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
        SBJ4(K)=-KI(IND,K)*PM4
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
        CKI1(K) = -C21(IND)*M1
        CKI21(K) = -C21(IND)*M2
        CKI22(K,K) = CMPLX(0.,0.)
         IF(IOSUB .EQ. 1) CKI22(K,K) = -C21(IND)*M4
        CKI3(K) = -C21(IND)*M3
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      CKI41(K)=-C21(IND)*PM4
        CKI42(K)=CMPLX(0.,0.)
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C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
  255 IF(ICAL .EQ. 1) GO TO 389
      IF(ICAL .EQ. 4) GO TO 389
      IF(ICAL .GT. 1 .AND. K .EQ. NIR) GO TO 23
C
C    * THE COMPONENTS OF THE PRESSURE DROP PERTURBATION IN EACH NODE
C
  389 CONTINUE
      DP1 = (1.-S/(COH(IND,K)*K1(IND,K))) * ALOG(ZETA(IND,K))
      DP2 = CEXP(DP1) - 1.
      DP3 = S*CKIN(IND,K) / GC
      DP4 = COH(IND,K)*K1(IND,K) - S
      DP1V = DP3 * (  TG(1,K)*ALOG(ZETA(IND,K))/(COH(IND,K)*K1(IND,K)) +
     1                TG(2,K)*DP2/DP4   )
      DP1Q = DP3 * (  (TG(3,K)*(ZETA(IND,K)-1.) + TG(4,K)*
     1    ALOG(ZETA(IND,K)))/(COH(IND,K)*K1(IND,K)) +TG(5,K)*DP2/DP4 )
      DP1H = DP3 * TG(6,K)*DP2/DP4
C
      DP2V = (TB2(1,K) - TB1(1,K)) / GC
      DP2Q = (TB2(2,K) - TB1(2,K)) / GC
      DP2H = (TB2(3,K) - TB1(3,K)) / GC
C
      SO1 = (CKIN(IND,K)*FRICMO(IND)*GO(IND)) / (GC*DENSF*DH(IND)*
     1      COH(IND,K)*K1(IND,K))
      DP5 = (2.*COH(IND,K)*K1(IND,K) - S) / (COH(IND,K)*K1(IND,K))
      DP6 = DP5 * ALOG(ZETA(IND,K))
      DP7 = CEXP(DP6) - 1.
      DP3V = SO1 * ( C8(IND,K)*ALOG(ZETA(IND,K))*TG(1,K) + C9(IND,K)*
     1      TG(1,K)*(ZETA(IND,K)-1.) + C8(IND,K)*TG(2,K)*COH(IND,K)*
     2      K1(IND,K)*DP2/DP4 + C9(IND,K)*TG(2,K)*DP7/DP5)
      DP3Q = SO1 * ( C8(IND,K)*TG(4,K)*ALOG(ZETA(IND,K)) + (C8(IND,K)
     1               *TG(3,K) + C9(IND,K)*TG(4,K))*(ZETA(IND,K)-1.)
     2               + (C9(IND,K)*TG(3,K)/2.)*(ZETA(IND,K)**2-1.)
     2               + C8(IND,K)*TG(5,K)*COH(IND,K)*K1(IND,K)*DP2/DP4
     3               + C9(IND,K)*TG(5,K)*DP7/DP5   )
      DP3H = SO1 * TG(6,K)* (  C8(IND,K)*COH(IND,K)*K1(IND,K)*DP2/DP4 +
     1              C9(IND,K)*DP7/DP5   )
C
      SO2 = CKIN(IND,K)*FRICMO(IND)*GO2(IND) / (2.*GC*DH(IND)*
     1      COH(IND,K)*K1(IND,K)*DENSF)
      DP4V = SO2 * (   TF(1,K)*(ZETA(IND,K)-1.) + TF(2,K)*
     1      ALOG(ZETA(IND,K))+ COH(IND,K)*K1(IND,K)*TF(3,K)*DP2/DP4
     2      + TF(4,K)*DP7/DP5    )
      DP4Q = SO2 * (   TF(5,K)*(ZETA(IND,K)-1.) + TF(6,K)*ALOG(
     1      ZETA(IND,K))+TF(7,K)*(ZETA(IND,K)**2-1.)/2. + COH(IND,K)
     2      *K1(IND,K)*TF(8,K)*DP2/DP4 + TF(9,K)*DP7/DP5   )
      DP4H = SO2 * (  COH(IND,K)*K1(IND,K)*TF(10,K)*DP2/DP4 + TF(11,K)*
     1                     DP7/DP5   )
C
      SO3 = G1*C4*CKIN(IND,K)*STC2(K)/GC
      DP5V = SO3 * (   (1.-1./ZETA(IND,K)) + (1./CSTB1(K)-1.)/STC1(K)   )
      DP5Q = -DP5V / (COH(IND,K)*K1(IND,K)) * CKIN(IND,K)
      DP5H = (SO3/STC2(K)/S) * (1./CSTB1(K)-1.)
C
      DP6V = ( (TR2(1,K)-TR1(1,K)) - TR2(2,K)*DP2/ZETA(IND,K)**2 ) / GC
      DP6Q = ( TR2(3,K)*(1.-ZETA(IND,K))-TR2(4,K)*DP2/ZETA(IND,K)**2 )
     1       / GC
      DP6H = (   TR2(5,K)/CSTB2(K) - TR1(5,K)   ) / GC
C
```

```
      G12V = DP1V + DP2V + DP3V + DP4V + DP5V +DP6V
      G12Q = DP1Q + DP2Q + DP3Q + DP4Q + DP5Q +DP6Q
      G12H = DP1H + DP2H + DP3H + DP4H + DP5H +DP6H
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      EDP1=(S+CZERO*K1(IND,K))/(CZERO*K1(IND,K))
      EDP2=-EDP1*ALOG(ZETA(IND,K))
      EDP3=CEXP(EDP2)
      DPP1=CKIN(IND,K)/(GC*CZERO*K1(IND,K))
      DPP2=FRICMO(IND)*GO(IND)/(DENSF*DH(IND))
      DP16P=(TR2(6,K)+TR2(7,K)*ZETA(IND,K)
     1      +TR2(8,K)/ZETA(IND,K)+TR2(9,K)/ZETA(IND,K)**2
     2      +TR2(10,K)*CEXP(EDP2)+TR2(11,K)*ALOG(ZETA(IND,K))
     3      +TR2(12,K)/ZETA(IND,K)**2*ALOG(ZETA(IND,K)))/GC
      DP17P=(TR1(6,K)+TR1(7,K)
     1      +TR1(8,K)+TR1(9,K)
     2      +TR1(10,K))/GC
C
      X=ZETA(IND,K)
      TC3=STC3(K)
      TC4=STC4(K)
      TC5=STC5(K)
      TC6=STC6(K)
      DP1P=DPP1*(S+DPP2*COR2PH(IND,K))*(TG(7,K)*(X-1.)+TG(8,K)/2.
     @ *(X**2-1.)+TG(9,K)*ALOG(X)+TG(10,K)/(2.-EDP1)*(X**2*EDP3-1.)
     @ +TG(11,K)/2.*(ALOG(X))**2)
      DP1P=DP1P-DPP1*DPP2/2.*GO(IND)/DENSF*DRF*(X-1.)
      DP2P=1./GC*2.*GO(IND)/DOOUT(IND,K)*(TG(7,K)+TG(8,K)*X+TG(9,K)/
     @ X
     @ +TG(10,K)*X*EDP3+TG(11,K)/X*ALOG(X))-1./GC*2.*GO(IND)
     @ /DOIN(IND,K)*(TG(7,K)
     @ +TG(8,K)+TG(9,K)+TG(10,K))+1./GC*C4*(GO(IND)/DOOUT(IND,K))**2
     @ *(TC3*(1.-EDP3)+TC4*(1./X-EDP3)+TC5*(1./X**2-EDP3)+TC6
     @ *(1./X**2*(ALOG(X)-1./(EDP1-2.))+EDP3/(EDP1-2.)))-1./GC*C4*
     @ (GO(IND)/DOIN(IND,K))**2/(EDP1-2.)
     @ *TC6-1./GC*GO(IND)**2*DDR*(ALOUT(IND,K)/DOOUT(IND,K)**2
     @ -ALPIN(IND,K)/DOIN(IND,K)**2)
      DP2P=DP2P-GO(IND)**2*(1./DOOUT(IND,K)**2-1./DOIN(IND,K)**2)
     @     *DRF/GC
      DP3P=DPP1/2.*GO(IND)*DPP2*(TF(12,K)*(X-1.)+TF(13,K)*ALOG(X)
     @ +TF(14,K)/2.*(X**2-1.)+TF(15,K)/3.*(X**3-1.)+TF(16,K)
     @ /(2.-EDP1)
     @ *(X**2*EDP3-1.)+TF(17,K)/(3.-EDP1)*(X**3-1.)+TF(18,K)*(X
     @ *(ALOG(X)-1.)+1.)+TF(19,K)/2.*(ALOG(X))**2)
      DP4P=DPP1*G1*(-C4)*(STC3(K)*(X-1.-1./(1.-EDP1)*(X*EDP3-1.))
     @ +STC4(K)*(ALOG(X)-(X*EDP3-1.)/(1.-EDP1))+STC5(K)*(1.-1./X
     @ -(X*EDP3-1.)/(1.-EDP1))+STC6(K)*(-(1.+ALOG(X))/X+1.+
     @ (X*EDP3-1.)
     @ /(1.-EDP1)/(EDP1-2.)+(1./X-1.)/(EDP1-2.)))
      C15=DENSF/(C4*COH(IND,K))
      DP4P=DP4P+DPP1*G1*(C15*DDR*(X-1.)-DDR*(C15-ALPIN(IND,K))
     @  *ALOG(X)+(X-1.)*DRF)
      G12P=DP1P+DP2P+DP3P+DP4P+DP16P-DP17P
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      VAR1 = C22(IND)
      MM4 = CMPLX(0.,0.)
      IF(IOSUB .EQ. 1 .AND. K .EQ. NTS) MM4 = VAR1*M4
      IF(K .GT. NTS) VAR1 = CMPLX(0.,0.)
C
C     ***  PRESSURE DROP TRANSFER FUNCTIONS OF THE TWO-PHASE REGION *
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```
C
      PINOD1(K) = GT2V*SBJ1(K)+GT2Q*SBM1(K)+GT2H*CK11(K) - VAR1*M1
C
       IF(NOSB .GT. 0) GO TO 2010
      DO 33 I=1,NSF
      CAUX=M2
      IF(IOSUB .NE. 0)CAUX=M2*(1.+SH2/(CPF*Z2))
      PINOD2(K,I) = (GT2V*SBJ21(K)+GT2H*CK121(K)+GT2Q*SBM21(K)
     1             -VAR1*CAUX) * HS(I)
   33 CONTINUE
 2010  IF(K .EQ. NTS) GO TO 2040
      KLOW=K-1
      DO 34 J=NTS,KLOW
      PINOD2(K,J) = GT2V*SBJ2(K,J) + GT2Q*SBM2(K,J) + GT2H*CK122(K,J)
      IF(IOSUB .NE. 0 .AND. K .GE. NFB2 .AND. J .EQ. K)PINOD2(K,K)
     @  =C5(IND)*Z3(K)*GT2Q
      IF(IOSUB .EQ. 0 .AND. K .GE. NTS .AND. J .EQ. K)PINOD2(K,K)
     @  =C5(IND)*Z3(K)*GT2Q
   34 CONTINUE
 2040 PINOD2(K,K) = SBM2(K,K)*GT2Q - MM4
C
      PINOD3(K) = GT2V*SBJ3(K)+GT2H*CK13(K)-VAR1*M3+GT2Q*SBM3(K)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      IF (K .EQ. NTS) GOTO 960
      PINOD4(K)=GT2H*CK141(K)+GT2P+GT2Q*SBM4(K)
     1          +GT2V*SBJ4(K)+GT2H*CK142(K)
      GOTO 964
960   PINOD4(K)=-VAR1*PM4+GT2V*SBJ4(K)+GT2Q*SBM4(K)+GT2P+GT2H*(
     @ CK141(K)+CK142(K))+GT2Q*C5(IND)*ZP(K)
964   CONTINUE
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      GO TO 999
   23 CONTINUE
 1000 CONTINUE
C
C    * TOTAL TWO-PHASE PRESSURE DROP PERTURBATION WHICH DOES NOT
C                       INCLUDE THE SPACER EFFECT
C
      SUMP1 = CMPLX(0.,0.)
      DO 36 I=1,NP1
   36 SUMP2(I) = CMPLX(0.,0.)
      SUMP3 = CMPLX(0.,0.)
      SUMP4=CMPLX(0.,0.)
C
      DO 35 K=NIS,NP1
      SUMP1 = SUMP1 + PINOD1(K)
      SUMP3 = SUMP3 + PINOD3(K)
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      SUMP4=SUMP4+PINOD4(K)
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
   35 CONTINUE
      DO 67 I=1,NP1
      DO 67 K=NIS,NP1
      SUMP2(I) = SUMP2(I) + PINOD2(K,I)
   67 CONTINUE
C
C    * CALCULATE THE PRESURE DROP PERTURBATION BY THE "SPACER"
C
      NSPAC = NIPSP(IND)
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285

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      NPLUS = NP1 + 1
      DO 37 K=NIS,NPLUS
      KK = K
      IF(K .EQ. NPLUS) GO TO 645
      NNSP = NUMBSP(IND,KK)
      IF(NNSP .EQ. 0) GO TO 37
  645 IF(K .EQ. NPLUS) NNSP = 1
      DO 377 JJJ=1,NNSP
      NSPAC = NSPAC + 1
C
       IF(K .EQ. NPLUS) GO TO 646
      SLOSS = KLOSS(NSPAC)
      GO TO 647
  646  Y2 = ZETA(IND,NP1)
       KK = NP1
       SLOSS = XKEXIT(IND)
       GO TO 648
  647 Y2 = ZETSP(IND,NSPAC)
  648 CONTINUE
      VV1 = -SIC1(KK) * ALOG(Y2)
      Y3 = CEXP(VV1)
      VV2 = (1. - SIC1(KK)) * ALOG(Y2)
      Y4 = CEXP(VV2)
      Y5 = SLOSS*GO2(IND) / (2.*GC*DENSF)
      Y6 = SLOSS*VIN(IND)*COR2PH(IND,KK)/GC
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      Y7=Y6*VIN(IND)/2.*DRF
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      SPA1 = Y6*(TG(1,KK)/Y2 + TG(2,KK)*Y3)
      SPA2 = Y6*(TG(3,KK) + TG(4,KK)/Y2 + TG(5,KK)*Y3)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPAPPPPPPPPPPPP
      SPA4=Y6*(TG(7,KK)+TG(8,KK)*Y2+TG(9,KK)/Y2+TG(10,KK)*Y3
     1      +TG(11,KK)/Y2*ALOG(Y2))
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      SPA3 = Y6*TG(6,KK)*Y3
      SPB1 = Y5*(TF(1,KK) + TF(2,KK)/Y2 + TF(3,KK)*Y3 + TF(4,KK)*Y4)
      SPB2 = Y5*(TF(5,KK) + TF(6,KK)/Y2 + TF(7,KK)*Y2 + TF(8,KK)*Y3
     1           + TF(9,KK)*Y4)
      SPB3 = Y5*(TF(10,KK)*Y3 + TF(11,KK)*Y4)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      SPB4=Y5*(TF(12,KK)+TF(13,KK)/Y2+TF(14,KK)*Y2+TF(15,KK)*Y2**2
     1       +TF(16,KK)*Y3+TF(17,KK)*Y4+TF(18,KK)*ALOG(Y2)
     2       +TF(19,KK)/Y2*ALOG(Y2))-Y7
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      B1 = SPA1 + SPB1
      B2 = SPA2 + SPB2
      B3 = SPA3 + SPB3
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      B4 = SPA4+SPB4
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      SPK1(NSPAC) = B1*SBJ1(KK) + B2*SBM1(KK) + B3*CKI1(KK)
       IF(NOSB .GT. 0) GO TO 2011
      DO 39 I=1,NSF
   39 SPK2(NSPAC,I) = (B1*SBJ21(KK) + B3*CKI21(KK) + B2*SBM21(KK))
     1                * HS(I)
 2011 DO 40 J=NTS,KK
      IF(J .EQ. KK) GO TO 41
      SPK2(NSPAC,J) = B1*SBJ2(KK,J) + B2*SBM2(KK,J) + B3*CKI22(KK,J)
      IF(IOSUB .NE. 0 .AND. KK .GE. NFB2 .AND. J .EQ. KK)SPK2(
     @  NSPAC,J)=C5(IND)*Z3(KK)*B2
      IF(IOSUB .EQ. 0 .AND. KK .GE. NTS .AND. J .EQ. KK)SPK2(
     @  NSPAC,J)=C5(IND)*Z3(KK)*B2
      GO TO 40
   41 SPK2(NSPAC,J) = B2*SBM2(KK,J)
   40 CONTINUE
      SPK3(NSPAC) = B1*SBJ3(KK) + B3*CKI3(KK) + B2*SBM3(KK)
      SPK4(NSPAC)=B3*CKI42(KK)
     1 +B3*CKI41(KK)+B4+B2*SBM4(KK)+B1*SBJ4(KK)+B2*ZP(KK)*C5(IND)
  377 CONTINUE
   37 CONTINUE
C
C     * TOTAL SPACER EFFECT
C
      SPT1 = CMPLX(0.,0.)
      DO 43 I=1,NP1
   43 SPT2(I) = CMPLX(0.,0.)
      SPT3 = CMPLX(0.,0.)
      SPT4 =CMPLX(0.,0.)
C
      KISP = K2PSP(IND)
      DO 44 J=KISP, NSPAC
      SPT1 = SPT1 + SPK1(J)
      SPT3 = SPT3 + SPK3(J)
      SPT4 =SPT4+SPX4(J)
   44 CONTINUE
      DO 46 I=1,NP1
      DO 46 J=KISP,NSPAC
      SPT2(I) = SPT2(I) + SPK2(J,I)
   46 CONTINUE
C
C     * TOTAL TWO-PHASE PRESSURE DROP PERTURBATION IN THE CORE
C
      PI1(IND) = SUMP1 + SPT1
      PI3(IND) = SUMP3 + SPT3
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      PI4(IND)=SUMP4+SPT4
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      DO 45 I=1,NP1
      PI2(IND,I) = SUMP2(I) + SPT2(I)
   45 CONTINUE
C
C     * CHANNEL EXIT FLOW VELOCITY & VOID FRACTION PERTURBATION
C
      CXJ1(IND) = SBJ1(NP1)
      CXJ3(IND) = SBJ3(NP1)
      CXA1(IND) = CKI1(NP1)
      CXA3(IND) = CKI3(NP1)
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      CXJ4(IND)=SBJ4(NP1)
      CXA4(IND)=CKI41(NP1)+CKI42(NP1)
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      IF(NOSB .GT. 0) GO TO 52
      DO 69 I=1,NSF
      CXJ2(IND,I) = SBJ21(NP1)*HS(I)
      CXA2(IND,I) = CKI21(NP1)*HS(I)
   69 CONTINUE
   52 MP1=NP1-1
```

```
      DO 53 I=NTS,NP1
      CXJ2(IND,I) = SBJ2(NP1,I)
      CXA2(IND,I) = CKI22(NP1,I)
   53 CONTINUE
      CXJ2(IND,NP1)=CMPLX(0.,0.)
      CXA2(IND,NP1)=CMPLX(0.,0.)
C
      IF(ICAL .EQ. 6) GO TO 8879
C.....................................................................
C   ***  CALCULATE VOID FRACTION PERTURBATION IN EACH NODE  ***
C.....................................................................
      DO 47 K=NTS,NP1
         DO 48 I=1,NP1
   48    TALP2(IND,K,I) = CMPLX(0.,0.)
C
      TALP1(IND,K) = (PAR1(K)*SBJ1(K)+PAR2(K)*SBM1(K)+PAR3(K)*CKI1(K))
       IF(NOSB .GT. 0) GO TO 2020
      DO 49 I=1,NSF
   49 TALP2(IND,K,I)=(CKI21(K)*PAR3(K)+PAR1(K)*SBJ21(K)+SBM21(K)*
     1             PAR2(K)) * HS(I)
 2020 DO 50 I=NTS,K
      IF(I .EQ. K) GO TO 51
      TALP2(IND,K,I)=PAR3(K)*CKI22(K,I)+PAR1(K)*SBJ2(K,I)+PAR2(K)*
     1             SBM2(K,I)
      GO TO 50
   51 IF(IOSUB .NE. 0 )TALP2(IND,K,I)
     @  =SBM2(K,I)*PAR2(I)
      IF(IOSUB .EQ. 0 )TALP2(IND,K,I)
     @  =C5(IND)*Z3(I)*PAR2(I)
   50 CONTINUE
      TALP3(IND,K) = PAR1(K)*SBJ3(K) + PAR3(K)*CKI3(K) + PAR2(K)*
     1           SBM3(K)
       TSUM2(IND,K) = CMPLX(0.,0.)
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
       TALP4(IND,K)=PAR4(K)
     1          +PAR3(K)*(CKI41(K)+CKI42(K))+PAR1(K)*SBJ4(K)
     2          +PAR2(K)*SBM4(K)
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      DO 55 J=1,K
      TSUM2(IND,K) = TSUM2(IND,K) + TALP2(IND,K,J)*BEE(IND,J)
   55 CONTINUE
   47 CONTINUE
C
C    * TRANSFER FUNCTION FOR THE CHANNEL AVERAGE VOID FRACTION
C
C     IF(ICAL .GE. 4) GO TO 8879
      TAU1(IND) = CMPLX(0.,0.)
      DO 61 K=1,NP1
   61 SUM2(K) = CMPLX(0.,0.)
      DO 62 K=NTS,NP1
      TAU1(IND) = TAU1(IND) + TALP1(IND,K)*DZ(IND,K)
   62 CONTINUE
      TAU1(IND) = TAU1(IND) / ALHEAT
      DO 64 K=1,NP1
      DO 63 J=K,NP1
   63 SUM2(K) = SUM2(K) + TALP2(IND,J,K)*DZ(IND,J)
      SUM2(K) = SUM2(K) / ALHEAT
   64 CONTINUE
C
      TAU2(IND) = CMPLX(0.,0.)
      DO 65 K=1,NP1
      TAU2(IND) = TAU2(IND) + SUM2(K)*BEE(IND,K)
   65 CONTINUE
C
 8879 RETURN
      END
C
C
C
C*******************************************************
C     VARIOUS FUNCTION
C*******************************************************
C
C..................................................................
      REAL FUNCTION HL(P,T)
C..................................................................
C    *           HL ;  LIQUID ENTHALPY  0-P-2120 PSIA
C     REAL HL
      HL = 0.001618*P - 47.62 + (0.965566 - 4.982E-6*P)*T+
     1  (8.2445*P - 8843.4)/(802.-T) + (6.6612*P-20392.)/(T - 750.)
      RETURN
      END
C
C.................................................................
      FUNCTION DENS(P,T,HPT)
C.................................................................
C    *           DENS ;   LIQUID DENSITY    0-P-2120 PSIA
      HPT = HL(P,T)
      IF(HPT .GE. 280.)    GO TO 100
      DENS = 2.14E-4*P +62.4 +(1.438E-9*P- 8.73F-5)*HPT**2
     1 + (2.32E-10 - 6.2E-15*P)*HPT**4
      RETURN
  100 DENS = 5.761E-4*P+92.924 + (1.6386*P+39440.2)/(HPT-(0.035704*P
     1 + 1377.35))
      RETURN
      END
C
C..................................................................
      FUNCTION  VF(P)
C.................................................................
C
      VF = 1.7087E-02 + 0.6925E-05*P - 0.4254E-08*P**2 + 0.2180E-11*
     @     P**3- 0.0357E-14*P**4
      RETURN
      END
C.................................................................
      FUNCTION DRFDP(P)                                          .
C.................................................................
      DVF=.6925E-05-.8508E-08*P+.654E-11*P**2-.1428E-14*P**3
      DRFDP=-DVF/VF(P)**2
      RETURN
      END
C
C.................................................................
      FUNCTION  VFG(P)
C.................................................................
C
      VFG = 2.6454 - 5.9326E-03*P + 6.5891E-06*P**2 - 3.9249E-09*P**3
     C     + 1.1897E-12*P**4 - 0.1441E-15*P**5
      RETURN
      END
C
C................................................................
      FUNCTION  HF(P)
C................................................................
C
      HF = 323.9128 + 0.2964306*P - 0.944149E-04*P**2
     C      + 0.165674E-07*P**3
      RETURN
      END
C
C................................................................
      FUNCTION HFG(P)
C................................................................
C
      HFG = 883.6608 - 0.2911105*P + 0.743325E-04*P**2
     C       - 0.165592E-07*P**3
      RETURN
      END
C
C...............................................................
      REAL FUNCTION MUTL(T)
C...............................................................
C     *         VISCOSITY OF SATURATED LIQUID WATER IN RANGE
C                                 32 TO 572 DEG. F(LBM/HR-FT)
C     *                    REF - ASME STEAM TABLES, PAGE 74
      MUTL  = 0.0584*10.0**(446.04/(207.6+T))
      RETURN
      END
C
C...............................................................
      FUNCTION COND(T)
C...............................................................
C     *         THERMAL CONDUCTIVITY OF SATURATED WATER IN RANGE
C                                 32 TO  622 DEG. F(BTU/HR-FT-DEG.F)
      DATA A0, A1, A2, A3, A4 /-0.53299, 1.6406,  -1.0404, 0.30378,
     1       -0.042433/
      TT = (T + 459.67)/491.67
      COND = A0 + A1*TT + A2*TT*TT + A3*TT**3 + A4*TT**4
      RETURN
      END
C
C
C................................................................
      REAL FUNCTION MARNEL(P,G)
C................................................................
C     *    CALCULATION OF PI(P,G) IN THE MARTINELLI-NELSON CORRELATION
C              FOR THE TWO-PHASE MULTIPLIER
      GHR = G*3600.
      G6 = GHR/1.E+06
      IF(G6 .GT. 0.7) GO TO 10
      MARNEL = 1.36 + 0.0005*P + 0.1*G6 - 0.000714*P*G6
      RETURN
C
   10 MARNEL = 1.26 - 0.0004*P + 0.119/G6 + 0.00028*P/G6
      RETURN
      END
C
C
C
```

```
C
      FUNCTION CONPI(X)
      IF(X .GE. 2.) GO TO 1
      CONPI = 1.
      GO TO 2
    1 CONPI = (X/0.61)**0.47
    2 RETURN
      END
C
C
C
C
      FUNCTION CCON(X)
      IF(X .GT. 145.) GO TO 1
      CCON = 61. - 6.389E-05*(X-1.7E+05)
      GO TO 2
    1 CCON = 0.23E+10*X**(-1.418)
    2 RETURN
      END
C
C..................................................................
       FUNCTION ANGL(COMP)
C..................................................................
       COMPLEX COMP
      FIMAG=AIMAG(COMP)
      DREAL=REAL(COMP)
      SREAL = DREAL**2
      SQMOD=FIMAG**2+DREAL**2
      IF(SREAL.LE.1.0E-30) GO TO 931
      ANGL=57.296*ATAN2(FIMAG,DREAL)
      RETURN
  931 ANGL=90.0
      IF(FIMAG.LE.0.0)ANGL=-90.0
      IF(SQMOD.LE.1.0E-30)ANGL=0.0
      RETURN
      END
C
C................................................................
      COMPLEX FUNCTION CCOTH(Z)
C................................................................
C    *        CALCULATE COTH(Z)    ,WHERE Z IS A COMPLEX VARIABLE
C
      COMPLEX Z
      IF(CABS(Z) .GE. 99.) GO TO 1
      CCOTH = (CEXP(Z)+CEXP(-Z)) / (CEXP(Z)-CEXP(-Z))
      GO TO 2
C
    1 CCOTH = CMPLX(1.,0.)
    2 RETURN
      END
C
C
C...............................................................
      COMPLEX FUNCTION EPOW(X,Z)
C...............................................................
C    * CALCULATE X**Z   ( Z ; COMPLEX VARIABLE )
C
      COMPLEX Z,Z1
      IF(X .EQ. 1.) GO TO 10
      Z1 = Z*ALOG(X)
      EPOW = CEXP(Z1)
      GO TO 20
   10 EPOW = CMPLX(1.,0.)
   20 RETURN
      END
C
C
C.............................................................
      COMPLEX FUNCTION BSI0(Z)
C.............................................................
C    *  MODIFIED BESSEL FUNCTION OF THE FIRST KIND OF ORDER ZERO
C                 I0(Z*SQRT(I)) = BER(Z) + I*BEI(Z)
C
      Z1 = BER(Z)
      Z2 = BEI(Z)
      BSI0 = CMPLX(Z1,Z2)
      RETURN
      END
C
C.............................................................
      COMPLEX FUNCTION BSI1(Z)
C.............................................................
C    *  MODIFIED BESSEL FUNCTION OF THE FIRST KIND OF ORDER ONE
C                 I1(Z*SQRT(I)) = BEI1(Z) - I*BER1(Z)
C                      WHERE  BEI1(Z) = (SQRT(2)/2) * (BER'(Z)+BEI'(Z))
C                             BER1(Z) = (SQRT(2)/2) * (BER'(Z)-BEI'(Z))
C
      BEI1 = 0.707107 * (BERS(Z) + BEIS(Z))
      BER1 = 0.707107 * (BERS(Z) - BEIS(Z))
C
      BSI1 = CMPLX(BEI1, -BER1)
      RETURN
      END
C
C.............................................................
      COMPLEX FUNCTION BSK0(Z)
C.............................................................
C    *  MODIFIED BESSEL FUNCTION OF THE SECOND KIND OF ORDER ZERO
C                 K0(Z*SQRT(I)) = RKER(Z) + I*RKEI(Z)
C
      Z1 = RKER(Z)
      Z2 = RKEI(Z)
      BSK0 = CMPLX(Z1,Z2)
      RETURN
      END
C
C.............................................................
      COMPLEX FUNCTION BSK1(Z)
C.............................................................
C    *  MODIFIED BESSEL FUNCTION OF THE SECOND KIND OF ORDER ONE
C                 K1(Z*SQRT(I)) = -RKEI1(Z) + I*RKER1(Z)
C                      WHERE  RKEI1(Z) = (SQRT(2)/2) * (RKER'(Z)+RKEI'(Z))
C                             RKER1(Z) = (SQRT(2)/2) * (RKER'(Z)-RKEI'(Z))
C
      REAL RKEI1, RKER1
      RKEI1 = 0.707107 * (RKERS(Z) + RKEIS(Z))
      RKER1 = 0.707107 * (RKERS(Z) - RKEIS(Z))
C
      BSK1 = CMPLX(-RKEI1, RKER1)
C
```

```
      RETURN
      END
C
C....................................................................
      FUNCTION BER(Z)
C....................................................................
C         ***   BER FUNCTION   ***
C
      DIMENSION P(7)
      DATA P/ -64.0     , 113.777778, -32.363457,   2.641914,
     1          -0.083496,   0.001226,  -0.000009/
      DATA PI/3.141593/
C
      IF(Z .GT. 10) GO TO 10
      Y = Z/8.
      BER = 1.
      DO 1 I=1,7
      I4 = 4 * I
      BER = BER + P(I)*Y**I4
    1 CONTINUE
      RETURN
C
C* ASYMPTOTIC SOLUTION FOR  Z>10
   10 Z1 = (PI/180.) * (40.514*Z + 67.5)
      Z2 = (PI/180.) * (40.514*Z + 22.5)
      BER = (0.3989*EXP(Z/1.414214)/SQRT(Z)) * (SIN(Z1)+SIN(Z2)/(8.*Z))
      RETURN
      END
C
C....................................................................
      FUNCTION BEI(Z)
C....................................................................
C         ***   BEI FUNCTION   ***
C
      DIMENSION P(7)
      DATA P/ 16.0     ,-113.777778,  72.817777, -10.567658,
                0.521856,  -0.011037,  +0.000113/
      DATA PI/3.141593/
C
      IF(Z .GT. 10) GO TO 10
      Y = Z/8.
      BEI = 0.
      DO 1 I=1,7
      II = 2 * (2*I - 1)
      BEI = BEI + P(I)*Y**II
      CONTINUE
      RETURN
C
C* ASYMPTOTIC SOLUTION FOR  Z>10
   10 Z1 = (PI/180.) * (40.514*Z - 22.5)
      Z2 = (PI/180.) * (40.514*Z - 67.5)
      BEI = (0.3989*EXP(Z/1.414214)/SQRT(Z)) * (SIN(Z1)+SIN(Z2)/(8.*Z))
      RETURN
      END
C
C....................................................................
      FUNCTION BEIS(Z)
C....................................................................
C         ***   BEI'  FUNCTION   ***
C
```

```
      DIMENSION P(6)
      DATA P/ -10.666667,  11.377778,  -2.311675,   0.146772,
     1          -0.003794,   0.000046/
      DATA PI/3.141593/
C
      IF(Z .GT. 10) GO TO 10
      Y = Z/8.
      BEIS = 0.5
      DO 1 I=1,6
      I4 = 4 * I
      BEIS = BEIS + P(I)*Y**I4
    1 CONTINUE
      BEIS = Z*BEIS
      RETURN
C
C* ASYMPTOTIC SOLUTION FOR  Z>10
   10 Z1 = (PI/180.) * (40.514*Z + 22.5)
      Z2 = (PI/180.) * (40.514*Z - 22.5)
      BEIS = (0.3989*EXP(Z/1.414214)/SQRT(Z))
     1                       * (SIN(Z1) - SIN(Z2)*(3./(8.*Z)))
      RETURN
      END
C
C..............................................................
      FUNCTION BERS(Z)
C..............................................................
C          ***   BER'  FUNCTION   ***
C
      DIMENSION P(7)
      DATA P/ -4.0       ,  14.222222,  -6.068148,  0.660478,
     1          -0.026093,   0.000460,  -0.000004/
      DATA PI/3.141593/
C
      IF(Z .GT. 10) GO TO 10
      Y = Z/8.
      BERS = 0.
      DO 1 I=1,7
      II = 2 * (2*I - 1)
      BERS = BERS + P(I)*Y**II
    1 CONTINUE
      BERS = Z*BERS
      RETURN
C
C* ASYMPTOTIC SOLUTION FOR  Z>10
   10 Z1 = (PI/180.) * (40.514*Z + 112.5)
      Z2 = (PI/180.) * (40.514*Z + 67.5)
      BERS = (0.3989*EXP(Z/1.414214)/SQRT(Z)) * (SIN(Z1)-SIN(Z2)
     1            *(3./(8.*Z)))
      RETURN
      END
C
C..............................................................
      REAL FUNCTION RKER(Z)
C..............................................................
C          ***   KER  FUNCTION   ***
C
      DIMENSION P(7)
      DATA P/-59.058197, 171.362721, -60.609775,   5.655391,
     1          -0.196363,   0.003097,  -0.000025/
      DATA PI/3.141593/
```

```
C
      IF(Z .GT. 10) GO TO 10
      IF(Z .LT. 1) GO TO 20
C
      X1 = Z/2.
      X = -ALOG(X1)*BER(Z) + (PI/4.)*BEI(Z)
      Y = Z/8.
      RKER = -0.577216
      DO 1 I=1,7
      I4 = 4 * I
      RKER = RKER + P(I)*Y**I4
    1 CONTINUE
      RKER = X + RKER
      RETURN
C
C     * ASYMPTOTIC SOLUTION FOR  Z>10
   10 Z1 = (PI/180.) * (40.514*Z + 112.5)
      Z2 = (PI/180.) * (40.514*Z - 22.5)
      RKER = (1.2533*EXP(-Z/1.414214)/SQRT(Z)) * (SIN(Z1)+SIN(Z2)
     1          /(8.*Z))
      RETURN
C
   20 A0 = 0.115932 - ALOG(Z)
      X = Z/2.
      RKER = A0 + (PI/4.)*X**2 - ((A0+3./2.)/4.)*X**4
     1            - (PI/144.)*X**6 + ((A0+25./12.)/576.)*X**8
      RETURN
      END
C
C...........................................................................
      REAL FUNCTION RKEI(Z)
C...........................................................................
C         ***   KEI  FUNCTION   ***
C
      DIMENSION P(7)
      DATA P/  6.764549,-142.918277, 124.235697, -21.300609,
     1          1.175091,  -0.026959,   0.000295/
      DATA PI/3.141593/
C
      IF(Z .GT. 10) GO TO 10
      IF(Z .LT. 1) GO TO 20
C
      X1 = Z/2.
      X = -ALOG(X1)*BEI(Z) - (PI/4.)*BER(Z)
      Y = Z/8.
      RKEI = 0.
      DO 1 I=1,7
      I1 = 2 * (2*I - 1)
      RKEI = RKEI + P(I)*Y**I1
    1 CONTINUE
      RKEI = X + RKEI
      RETURN
C
C     * ASYMPTOTIC SOLUTION FOR  Z>10
   10 Z1 = (PI/180.) * (40.514*Z + 22.5)
      Z2 = (PI/180.) * (40.514*Z + 67.5)
      RKEI = (1.2533*EXP(-Z/1.414214)/SQRT(Z)) * (-SIN(Z1)+SIN(Z2)
     1          /(8.*Z))
      RETURN
C     * FOR  Z<1
```

```
   20 A0 = 0.115932 - ALOG(Z)
      X = Z/2.
      RKEI = -PI/4. + (A0+1.)*X**2 - (PI/16.)*X**4
     1          - ((A0+11./6.)/36.)*X**6 + (PI/2304.)*X**8
      RETURN
      END
C
C.................................................................
      REAL FUNCTION RKEIS(Z)
C.................................................................
C          ***   KEI'  FUNCTION   ***
C
      DIMENSION P(6)
      DATA P/-13.398589,  19.411828,  -4.659508,   0.330494,
     1        -0.009267,   0.000120/
      DATA PI/3.141593/
C
      IF(Z .GT. 10) GO TO 10
      IF(Z .LT. 1) GO TO 20
C
      XI = Z/2.
      X = -ALOG(XI)*BEIS(Z) -BEI(Z)/Z - (PI/4.)*BERS(Z)
      Y = Z/8.
      RKEIS = 0.211392
      DO 1 I=1,6
      I4 = 4 * I
      RKEIS = RKEIS + P(I)*Y**I4
    1 CONTINUE
      RKEIS = X + Z*RKEIS
      RETURN
C
C     * ASYMPTOTIC SOLUTION FOR  Z>10
   10 Z1 = (PI/180.) * (40.514*Z - 22.5)
      Z2 = (PI/180.) * (40.514*Z + 22.5)
      RKEIS = (1.2533*EXP(-Z/1.414214)/SQRT(Z)) * (SIN(Z1)+SIN(Z2)
     1          *(3./(8.*Z)))
      RETURN
C     * FOR  Z<1
   20 A0 = 0.115932 - ALOG(Z)
      X = Z/2.
      RKEIS = (A0+0.5)*X + PI*X**3/8. - (A0+5./3.)*X**5/12.
     1          - (PI*X**7)/576.
      RETURN
      END
C
C.................................................................
      REAL FUNCTION RKERS(Z)
C.................................................................
C          ***   KER'  FUNCTION   ***
C
      DIMENSION P(7)
      DATA P/ -3.691137,  21.420340, -11.364333,   1.413848,
     1        -0.061364,   0.001161,  -0.000011/
      DATA PI/3.141593/
C
      IF(Z .GT. 10) GO TO 10
      IF(Z .LT. 1) GO TO 20
C
      XI = Z/2.
      X = -ALOG(XI)*BERS(Z) -BER(Z)/Z + (PI/4.)*BEIS(Z)
      Y = Z/8.
      RKERS = 0.
      DO 1 I=1,7
      II = 2 * (2*I - 1)
      RKERS = RKERS + P(I)*Y**II
    1 CONTINUE
      RKERS = X + Z*RKERS
      RETURN
C
C     * ASYMPTOTIC SOLUTION FOR  Z>10
   10 Z1 = (PI/180.) * (40.514*Z + 67.5)
      Z2 = (PI/180.) * (40.514*Z + 112.5)
      RKERS = -(1.2533*EXP(-Z/1.414214)/SQRT(Z)) * (SIN(Z1)+SIN(Z2)
     1          *(3./(8.*Z)))
      RETURN
C     * FOR  Z<1
   20 A0 = 0.115932 - ALOG(Z)
      X = Z/2.
      RKERS = -(0.5/X) + PI*X/4. - (A0+5./4.)*0.5*X**3
     1          - (PI*X**5)/48. + (A0+47./24.)*X**7/144.
      RETURN
      END
C
C
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C CALCULATE STATE PARAMETERS FROM KAPL FITS
C ................................................................
      FUNCTION DVG1(P)
C ................................................................
      DVG1=-5.9319E-3+1.3177E-5*P-1.1768E-8*P**2
     1       +4.772E-12*P**3-7.205E-16*P**4
      RETURN
      END
C
C ................................................................
      FUNCTION DHF1(P)
C ...............................................................
      DHF1=0.2964306-1.888298E-4*P-4.97022E-8*P**2
      RETURN
      END
C
C ................................................................
      FUNCTION DHG1(P)
C ................................................................
      DHG1=0.00532-4.01648E-5*P+2.46E-11*P**2
      RETURN
      END
C
C ................................................................
      FUNCTION DCZER1(RHOG,DENSF,DRHOG,ION)
C ................................................................
      IF(ION .EQ. 0 ) GOTO 10
      DCZER1=-0.1/(DENSF*RHOG)**.5*(DRHOG-RHOG/DENSF*DRFDP(P))
      GOTO 100
   10 DCZER1=0.0
  100 RETURN
      END
C
C ................................................................
```

```
      FUNCTION DVGJ1(RHOG,DENSF,DRHOG,TAVE,P,ION)
C ...............................................................
      IF(ION .EQ. 0)GOTO 10
      SIGMA=-9.14285E-6*TAVE+6.2E-3
      DSDP=-9.14285E-6*.5*DTSDP(P)
      DVGJ1=.725*1/(((((DENSF-RHOG)*SIGMA*32.2*32.2)/DENSF**2)**.75)
     1     *(-SIGMA*32.2*32.2/DENSF**2)*(DRHOG-(DENSF-RHOG)*
     @       DSDP/SIGMA-DRFDP(P)*(2.*RHOG/DENSF-1.))
      GOTO 100
10    DVGJ1=0.0
100   RETURN
      END
C
C..............................................................
      FUNCTION DRGDP(P)
C..............................................................
C
      DVGDP=-5.9319E-3+13.1774E-6*P-11.7681E-9*P**2
     @ +4.7572E-12*P**3-.7205E-15*P**4
      DRGDP=-DVGDP/(VFG(P)+VF(P))**2
      RETURN
      END
C
C..............................................................
      FUNCTION DVFGDP(P)
C..............................................................
C
      DVFGDP=-5.9319E-3+13.1774E-6*P-11.7681E-9*P**2
     @ +4.7572E-12*P**3-.7205E-15*P**4
      RETURN
      END
C
C..............................................................
      FUNCTION DTSDP(P)
C..............................................................
C
      DATA B2,B3,B4,B5/65.14, 24.859, -4.3391, 1.6889/
      X=ALOG10(P)
      DXDP=1./(P*ALOG10(P))
      DTSDP=DXDP*(B2+2.*B3*X+3.*B4*X**2+4.*B5*X**3)
      RETURN
      END
C
C..............................................................
      FUNCTION DHFGDP(P)
C..............................................................
C
      DHFGDP=DHG1(P)-DHF1(P)
      RETURN
      END
C
C
C
C
      FUNCTION SGMA(P,TF)
C     ... SURFACE TENSION OF WATER(LBF/FT) AS FUNCTION OF PRESSURE
C       & SATURATED WATER TEMPERATURE
      DIMENSION A(5)
      DATA A/1.1609368E-01, 1.1214046E-03, -5.7528051E-06,
     1       1.2862746E-08, -1.1497192E-11/
```

```
C
      SGMA = -1.0
      TR = (TF-32.0)*0.555555
      IF(TR .LT. 0. .OR. TR .GT. 374.15) GO TO 20
      TKMT = 374.15 - TR
      TKMTS = TKMT**2
      SGMA = (A(1)*TKMTS) / (1.0+0.83*TKMT)
      DO 10 N=2,5
      SGMA = SGMA + A(N)*TKMTS
      TKMTS = TKMTS*TKMT
   10 CONTINUE
      SGMA = SGMA*0.68524E-04
   20 CONTINUE
C
      RETURN
      END
C
C
C
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      COMPLEX FUNCTION GIFN1(A,B,Y)
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C     * CALCULATION OF INCOMPLETE GAMMA FUNCTION
C
      COMPLEX A, B, Y
      COMPLEX*16 Z1, Z(100), X1, Z2, Z3, T1
      DOUBLE PRECISION F1,F2,DREAL,DIMAG,DIFF1,DIFF2
C
      Z2 = 1. + Y
      Z1 = CEXP(-B)/B
      X1 = (A-1.)/B
      Z(1) = (1.-CEXP(-Y)) + X1*(1.-CEXP(-Y)*Z2)
      N = 1
  300 N = N+1
      IF(N .GT. 100) GO TO 100
      N1 = N-1
      X1 = X1*(A-FLOAT(N))/B
      F1 = FLOAT(N) + 1
      F2 = DGAMMA(F1)
      Z3 = FLOAT(N)*CLOG(Y)
      Z2 = Z2 + CDEXP(Z3)/F2
      T1 = 1.-CEXP(-Y)*Z2
      IF(CDABS(T1) .LE. 1.0E-06) T1 = CMPLX(0.,0.)
      Z(N) = Z(N1) + X1*T1
C
       IF(DREAL(Z(N)) .LE. 1.0E-06) GO TO 402
      DIFF1 = (DREAL(Z(N))-DREAL(Z(N1))) / DREAL(Z(N))
      DIFF1 = DABS(DIFF1)
      GO TO 403
  402 DIFF1 = DREAL(Z(N)) - DREAL(Z(N1))
      DIFF1 = DABS(DIFF1)
  403  IF(DIMAG(Z(N)) .LE. 1.0E-06) GO TO 400
      DIFF2 = (DIMAG(Z(N))-DIMAG(Z(N1))) / DIMAG(Z(N))
      DIFF2 = DABS(DIFF2)
       GO TO 401
  400 DIFF2 = DIMAG(Z(N)) - DIMAG(Z(N1))
      DIFF2 = DABS(DIFF2)
  401 IF(DIFF1 .LE. 1.0E-04 .AND. DIFF2 .LE. 1.0E-04) GO TO 200
      GO TO 300
C
```

```
  200 GIFN1 = Z1*Z(N)
      GO TO 201
  100 WRITE(6,10)
   10 FORMAT(/5X,'***  GAMMA FUNCTION DIVERGE  ***')
      STOP
  201 RETURN
      END
C
C
C
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      COMPLEX FUNCTION GIFN2(A,CB,CZ)
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C    * CALCULATION OF INTEGRAL OF THE PRODUCT OF POWERS &
C                  EXPONENTIAL FUCTION
C
      COMPLEX A
      COMPLEX*16 C(100), F3, P1
      DOUBLE PRECISION B,Z,Q1,F1,F2,DREAL,DIMAG,DIFF1,DIFF2
C
      B = DBLE(CB)
      Z = DBLE(CZ)
      P1 = CDEXP((A-1.)*DLOG(B))
      Q1 = B*Z
      IF(REAL(1.-A).EQ.0. .AND. AIMAG(1.-A).EQ.0.) GO TO 305
      IF(REAL(2.-A).EQ.0. .AND. AIMAG(2.-A).EQ.0.) GO TO 306
      C(1) = (CDEXP((1.-A)*DLOG(Q1))-CDEXP((1.-A)*DLOG(B)))/(1.-A)
     1     + (CDEXP((2.-A)*DLOG(Q1))-CDEXP((2.-A)*DLOG(B)))/(2.-A)
      GO TO 307
  305 C(1) = DLOG(Q1/B) + (CDEXP((2.-A)*DLOG(Q1))-
     1                     CDEXP((2.-A)*DLOG(B)))/(2.-A)
      GO TO 307
  306 C(1) = (CDEXP((1.-A)*DLOG(Q1))-CDEXP((1.-A)*DLOG(B)))/(1.-A)
     1         + DLOG(Q1/B)
  307 N = 1
  300 N = N+1
      IF(N .GT. 100) GO TO 100
      N1 = N-1
      F1 = FLOAT(N) + 1
      F2 = DGAMMA(F1)
      F3 = F1 - A
      IF(DREAL(F3).EQ.0. .AND. DIMAG(F3).EQ.0.) GO TO 301
      C(N) = C(N1) + (CDEXP(F3*DLOG(Q1))-CDEXP(F3*DLOG(B)))
     1               / (F3*F2)
      GO TO 302
  301 C(N) = C(N1) + DLOG(Q1/B)
C
  302  IF(DREAL(C(N)) .LE. 1.0E-06) GO TO 402
      DIFF1 = (DREAL(C(N))-DREAL(C(N1))) / DREAL(C(N))
      DIFF1 = DABS(DIFF1)
      GO TO 403
  402 DIFF1 = DREAL(C(N)) - DREAL(C(N1))
      DIFF1 = DABS(DIFF1)
  403  IF(DIMAG(C(N)) .LE. 1.0E-06) GO TO 400
      DIFF2 = (DIMAG(C(N))-DIMAG(C(N1))) / DIMAG(C(N))
      DIFF2 = DABS(DIFF2)
       GO TO 401
  400 DIFF2 = DIMAG(C(N)) - DIMAG(C(N1))
      DIFF2 = DABS(DIFF2)
  401 IF(DIFF1 .LE. 1.0E-04 .AND. DIFF2 .LE. 1.0E-04) GO TO 200
```

```
      GO TO 300
C
  200 GIFN2 = PI*C(N)
      GO TO 201
  100 WRITE(5,10)
   10 FORMAT(/5X,'***  EXP & POW INTEGRAL IS DIVERGE  ***')
      STOP
  201 RETURN
      END
C SVD PROGRAM
C
C
      SUBROUTINE SVD(NM,M,N,A,W,MATU,U,MATV,V,IERR,RV1)
      DIMENSION A(NM,N),W(N),U(NM,N),V(NM,N),RV1(N)
      LOGICAL MATU,MATV
      IERR=0
      DO 100 I=1,M
      DO 100 J=1,N
      U(I,J)=A(I,J)
  100 CONTINUE
      G=0.0
      SCALE=0.0
      ANORM=0.0
      DO 300 I=1,N
      L=I+1
      RV1(I)=SCALE*G
      G=0.0
      S=0.0
      SCALE=0.0
      IF(I .GT. M)GO TO 210
      DO 120 K=I,M
  120 SCALE=SCALE+ABS(U(K,I))
      IF(SCALE .EQ. 0.0)GO TO 210
      DO 130 K=I,M
      U(K,I)=U(K,I)/SCALE
      S=S+U(K,I)**2
  130 CONTINUE
      F=U(I,I)
      G=-SIGN(SQRT(S),F)
      H=F*G-S
      U(I,I)=F-G
      IF(I .EQ. N)GO TO 190
      DO 150 J=L,N
      S=0.0
      DO 140 K=I,M
  140 S=S+U(K,I)*U(K,J)
      F=S/H
      DO 150 K=I,M
      U(K,J)=U(K,J)+F*U(K,I)
  150 CONTINUE
  190 DO 200 K=I,M
  200 U(K,I)=SCALE*U(K,I)
  210 W(I)=SCALE*G
      G=0.0
      S=0.0
      SCALE=0.0
      IF(I .GT. M .OR. I .EQ. N)GO TO 290
      DO 220 K=L,N
  220 SCALE=SCALE+ABS(U(I,K))
      IF(SCALE .EQ. 0.0)GO TO 290
      DO 230 K=L,N
      U(I,K)=U(I,K)/SCALE
      S=S+U(I,K)**2
  230 CONTINUE
      F=U(I,L)
      G=-SIGN(SQRT(S),F)
      H=F*G-S
      U(I,L)=F-G
      DO 240 K=L,N
  240 RV1(K)=U(I,K)/H
      IF(I .EQ. M)GO TO 270
      DO 260 J=L,M
      S=0.0
      DO 250 K=L,N
  250 S=S+U(J,K)*U(I,K)
      DO 260 K=L,N
      U(J,K)=U(J,K)+S*RV1(K)
  260 CONTINUE
  270 DO 280 K=L,N
  280 U(I,K)=SCALE*U(I,K)
  290 ANORM=AMAX1(ANORM,ABS(W(I))+ABS(RV1(I)))
  300 CONTINUE
      IF(.NOT. MATV)GO TO 410
      DO 400 II=1,N
      I=N+1-II
      IF(I .EQ. N)GO TO 390
      IF(G .EQ. 0.0)GO TO 360
      DO 320 J=L,N
  320 V(J,I)=(U(I,J)/U(I,L))/G
      DO 350 J=L,N
      S=0.0
      DO 340 K=L,N
  340 S=S+U(I,K)*V(K,J)
      DO 350 K=L,N
      V(K,J)=V(K,J)+S*V(K,I)
  350 CONTINUE
  360 DO 380 J=L,N
      V(I,J)=0.0
      V(J,I)=0.0
  380 CONTINUE
  390 V(I,I)=1.0
      G=RV1(I)
      L=I
  400 CONTINUE
  410 IF(.NOT. MATU)GO TO 510
      MN=N
      IF(M .LT. N)MN=M
      DO 500 II=1,MN
      I=MN+1-II
      L=I+1
      G=W(I)
      IF(I .EQ. N)GO TO 430
      DO 420 J=L,N
  420 U(I,J)=0.0
  430 IF(G .EQ. 0.0)GO TO 475
      IF(I .EQ. MN)GO TO 460
      DO 450 J=L,N
      S=0.0
      DO 440 K=I,M
  440 S=S+U(K,I)*U(K,J)
```

```
      F=(S/U(I,I))/G
      DO 450 K=I,M
      U(K,J)=U(K,J)+F*U(K,I)
  450 CONTINUE
  460 DO 470 J=I,M
  470 U(J,I)=U(J,I)/G
      GO TO 490
  475 DO 480 J=I,M
  480 U(J,I)=0.0
  490 U(I,I)=U(I,I)+1.0
  500 CONTINUE
  510 DO 700 KK=1,N
      K1=N-KK
      K=K1+1
      ITS=0
  520 DO 530 LL=1,K
      L1=K-LL
      L=L1+1
      IF(ABS(RV1(L))+ANORM .EQ. ANORM)GO TO 565
      IF(ABS(W(L1))+ANORM .EQ. ANORM)GO TO 540
  530 CONTINUE
  540 C=0.0
      S=1.0
      DO 560 I=L,K
      F=S*RV1(I)
      RV1(I)=C*RV1(I)
      IF(ABS(F)+ANORM .EQ. ANORM)GO TO 565
      G=W(I)
      H=SQRT(F*F+G*G)
      W(I)=H
      C=G/H
      S=-F/H
      IF(.NOT. MATU)GO TO 560
      DO 550 J=1,M
      Y=U(J,L1)
      Z=U(J,I)
      U(J,L1)=Y*C+Z*S
      U(J,I)=-Y*S+Z*C
  550 CONTINUE
  560 CONTINUE
  565 Z=W(K)
      IF(L .EQ. K)GO TO 650
      IF(ITS .EQ. 30)GO TO 1000
      ITS=ITS+1
      X=W(L)
      Y=W(K1)
      G=RV1(K1)
      H=RV1(K)
      F=((Y-Z)*(Y+Z)+(G-H)*(G+H))/(2.0*H*Y)
      G=SQRT(F*F+1.0)
      F=((X-Z)*(X+Z)+H*(Y/(F+SIGN(G,F))-H))/X
      C=1.0
      S=1.0
      DO 600 I1=L,K1
      I=I1+1
      G=RV1(I)
      Y=W(I)
      H=S*G
      G=C*G
      Z=SQRT(F*F+H*H)
      RV1(I1)=Z
      C=F/Z
      S=H/Z
      F=X*C+G*S
      G=-X*S+G*C
      H=Y*S
      Y=Y*C
      IF( .NOT. MATV)GO TO 575
      DO 570 J=1,N
      X=V(J,I1)
      Z=V(J,I)
      V(J,I1)=X*C+Z*S
      V(J,I)=-X*S+Z*C
  570 CONTINUE
  575 Z=SQRT(F*F+H*H)
      W(I1)=Z
      IF(Z .EQ. 0.0)GO TO 580
      C=F/Z
      S=H/Z
  580 F=C*G+S*Y
      X=-S*G+C*Y
      IF(.NOT. MATU)GO TO 600
      DO 590 J=1,M
      Y=U(J,I1)
      Z=U(J,I)
      U(J,I1)=Y*C+Z*S
      U(J,I)=-Y*S+Z*C
  590 CONTINUE
  600 CONTINUE
      RV1(L)=0.0
      RV1(K)=F
      W(K)=X
      GO TO 520
  650 IF(Z .GE. 0.0)GO TO 700
      W(K)=-Z
      IF(.NOT. MATV)GO TO 700
      DO 690 J=1,N
  690 V(J,K)=-V(J,K)
  700 CONTINUE
      GO TO 1001
 1000 IERR=K
 1001 RETURN
      END
End of file
```

NUFREQ-NP FORTRAN LISTING

PART II

```
C
C     ****************************************************************
C     *            NUCLEAR PROGRAM SYSTEM IN NUFREQ-NP               *
C     ****************************************************************
C
C             ; 1)  BWR STABILITY ANALYSIS CODE
C               2)  MODIFIED NUFREQ CODE
C               3)  TREAT NONUNIFORM HEAT FLUX BY NODAL METHOD
C               4)  HEATED WALL DYNAMICS FOR VARIOUS GEOMETRY
C               5)NEUTRON KINETICS WITH NODAL METHOD
C
C      ******* INPUT DESCRIPTION  FOR  NUFREQ-N ******************
C
C      * NODES - TOTAL NUMBER OF NODES IN AXIAL DIRECTION
C          1) NODES = 1 ; SINGLE NODE
C      * NCH - TOTAL NUMBER OF CHANNELS IN THE CORE
C      * NSP - TOTAL NUMBER OF SPACER IN A CHANNEL
C      * ISPEC - # OF ROW OF CONCERNED CANNEL
C      * JSPEC - # OF COLUMN OF CONCERNED CHANNEL
C      * NBB - THE END NODE OF THE SINGLE-PHASE REGION
C      * NBB1 - THE BEGINNING NODE OF THE TWO-PHASE REGION
C      * NP1 - THE TOTAL # OF REASSIGNED NODES
C
C      * OPTION
C          1) IOSUB ; TREATMENT OF SUBCOOLED BOILING
C               = 0 ; NO SUBCOOLED BOILING
C               = 1 ; TREAT SUBCOOLED BOILING
C          2) IOHW ; HEATED WALL DYNAMICS
C               = 0 ; LAMPED PARAMETER MODEL
C               = 1 ; PARALLEL HEATER
C               = 2 ; CYLINDRICAL HEATER
C               = 3 ; BWR REACTOR CHANNEL
C          3) IO2Q ; PERTURBATION OF Q''' IN TWO-PHASE REGION
C               = 0 ; NOT INCLUDED
C               = 1 ; INCLUDED
C          4) IK ; OPTION OF NUCLEAR COUPLING
C               = 0 ; NOT COUPLING
C               = 1 ; COUPLING
C          5) ISI ; NUMBER OF SIGNIFICANT FIGURE IN ROUNDING VALUE OF
C                   PERIOD   ( DEFAULT = 2)
C          6) IREQ
C               = 0 ; WMULT IS TO BE MODIFIED
C               = 1 ; WMULT IS TO BE SIMPLY MULTIPIED
C               = 2 ; WMULT IS TO BE SIMPLY ADDED
C          7) IPRINT ; PRINT MODE FOR THE STEADY-STATE PARAMETERS
C               = 0 ; NO PRINT STEADY-STATE VALUES
C               = 1 ; ONLY PRESSURE DROP OF EACH NODE & CHANNEL
C               = 2 ; ONLY VOID FRACTION & RELEVANT PARAMETERS
C               = 3 ; ONLY CHANNEL GEOMETRY
C               = 4 ; VOID FRACTION & PRESSURE DROP
C               = 5 ; VOID FRACTION, PRESSURE DROP, AXIAL POWER & HEAT
C                     FLUX DISTRIBUTION
C               = 6 ; ALL STEADY-STATE PARAMETERS
C          7) IBODE
C               = 0 ; OPEN-LOOP TRANSFER FUNCTION(GH) FOR NYQUIST PLOT
C               = 1 ; CLOSED-LOOP T. F. FOR POWER TO REACTIVITY
C               = 2 ; CLOSED LOOP T. F. FOR CORE EXTERNAL POWER
C                     PERTURBATION TO CORE FEEDBACK POWER PERTURBATION
C          8) IPHO
C               = 0 ; c1 & c2 of two-phase multiplier is fixed
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C                = 1 ; fitted by Martinelli Nelson model
C          9) ISLIP
C                = 0 ; c0(j) & vgj(j) are uniform for every nodes
C                = 1 ; fitted by Okawa & Lahey model
C         10) ICAL
C                = 0 ; ONLY STEADY-STATE CALCULATION
C                = 1 ; PARALLEL-CHANNEL STABILITY ANALYSIS
C                = 2 ; LOOP STABILITY ANALYSIS WITHOUT DELHI
C                = 3 ; SAME AS ICAL=2, BUT WITH DELHI
C                = 4 ; POWER-TO-VOID FRACTION TRANSFER FUNCTION CALCULATION
C                = 5 ; 4 WITH INLET ENTHALPY FEEDBACK
C                = 6 ; POWER-TO-FLOW TRANSFER FUNCTION
C         11) IRW
C                = 0 ; NO CHANNEL INLET FLOW RATE REDISTRIBUTION
C                      VEL3D(I) = JI0(I)
C                = 1 ; CHANNEL INLET FLOW RATE REDISTRIBUTION
C                      VEL3D(I) ; INITIAL GUESSED VALUE FOR JI0(I)
C
C       * SYSTEM(CORE) PARAMETER
C          1) P(PSIA) ; SYSTEM PRESSURE
C          2) TIN('F) ; INLET COOLANT TEMPRATURE
C          3) WIN ; TOTAL CORE INLET FLOW RATE
C          4) ALHEAT(FT) ; HEATED CHANNEL LENGTH (ACTIVE FUEL LENGTH)
C          5) TSATP('F) ; SATURATION TEMP. CORRESPONDING TO P
C          6) KEFF ; EFFECTIVE MULTIPLICATION FACTOR
C          7) AVEQ ; CORE-AVERAGED POWER DENSITY (BTU/S-FT3)
C          8) FOR THE RISER
C             A) COR ; CZERO FOR THE RISER
C             B) VGJR ; THE DRIFT VELOCITY FOR THE RISER
C             C) LR ; THE TOTAL CHANNEL LENGTH INCLUDING THE RISER
C             D) AR ; THE FLOW AREA OF THE RISER
C             E) DHIN ; THE HYDRAULIC DIAMETER OF THE RISER (IN)
C          9) FOR THE UPPER PLENUM
C             A) RP0 ; CURVATURE OF THE UPPER PLENUM
C             B) RP1 ; THE LENGTH OF REGION I
C             C) RP2 ; THE LENGTH OF REGION II
C             D) AP ; FLOW AREA OF THE UPPER PLENUM
C         10) FOR THE LOOP
C             A) SLOOP ; SUM OF (LI/AI) FOR I = 1,N, EQUIVALENT INERTIA
C                        OF LOOP (FT-1)
C             B) SFLOOP ; SUM OF FI*LI/(DHI*AI**2) FOR I = 1,N, EQUIVALENT
C                            FRICTIONAL RESISTANCE OF LOOP   (FT-4)
C                        LI - SEGMENT LENGTH, AI - SEGMENT FLOW AREA
C                        FI = SEGMENT FRICTION FACTOR
C                        DHI - SEGMENT HYDRAULIC DIAMETER
C             C) AA ; SLOPE OF PUMP CURVE (LBF/FT2 / LBM/S)
C                            (GIVEN ABSOLUTE VALUE)
C             D) HFW ; ENTHALPY OF THE FEED WATER
C             E) RFW ; THE RATIO OF FEEDWATER FLOW RATE TO CORE INLET FLOW RATE
C             F) W0 ; CORE TOTAL FLOW RATE
C
C       * CHANNEL PARAMETR
C          1) VCH(FT/S) ; STEADY-STATE CONCERNED CHANNEL INLET FLOW VELOCITY
C          2) PH(FT) ; HEATED PERIMETER OF CHANNEL
C          3) AXS(FT**2) ; CHANNEL FLOW AREA
C          4) DHIN(IN) ; CHANNEL HYDRAULIC DIAMETER
C          5) EXLOSS ; LOSS COEFFICIENT AT EXIT OF HEATED CHANNEL
C          6) INLOSS ; LOSS COEFFICIENT AT INLET OF HEATED CHANNEL
C          7) CPF ; SPECIFIC HEAT OF WATER
C          8) CXF ; CROSS-SECTIONAL AREA OF HEATER
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C           9) AXIAL NODE PARAMETERS
C               A) DZ(I) ; NODE LENGTH     (FT)
C               B) QDIS(I) ; CONSTANT STEADY-STATE NODE VOLUMETRIC HEAT
C                                                 (BTU/FT3-SEC)
C               C) QO(I) ; CONSTANT STEADY-STATE NODE HEAT FLUX(BTU/FT3
C                                                 (BTU/FT2-SEC)
C               D) CZERO ; CO IN VOID-QUALITY EQUATION
C               E) VGJ   ; DRIFT VELOCITY
C               F) CHOMO1,2 ; CORRECTION FACTOR FOR HOMO. TWO-PHASE
C                         MULTIPLIER
C               G) CHALF ; CHANNEL AVERAGE VOID FRACTION IN STEADY-STATE
C           CKIN(I) ; INLET KINEMATIC WAVE VELOCITY
C           CKOUT(I) ; EXIT KINEMATIC WAVE VELOCITY
C           ZETA(I) ; INLET WAVE VEL./EXIT WAVE VEL.
C           JOIN(I) ; INLET FLOW VELOCITY
C           DOIN(I) ; INLET DENSITY
C           DOOUT(I) ; EXIT DENSITY
C           ALPIN(I) ; INLET VOID FRACTION
C           ALPOUT(I) ; EXIT VOID FRACTION
C           ALFAVE(I) ; AVERAGE VOID FRACTION
C
C        * PARAMETER FOR HEATED WALL DYNAMICS
C           1) IOHW = 0 ; FOR LUMPED PARAMETER MODEL
C               A) CPF ; SPECIFIC HEAT OF HEATER
C               B) DENSH ; HEATER DENSITY
C           2) IOHW = 1 ; FOR PARALLEL PLATE
C               A) CPF ; SPECIFIC HEAT OF HEATER
C               B) TKH ; THERMAL CONDUCTIVITY OF HEATER
C               C) DENSH ; HEATER DENSITY
C               D) THICKH ; PLATE THICKNESS
C           3) IOHW = 2 ; FOR CYLINDRICAL TUBE
C               A) CPF ; SPECIFIC HEAT OF HEATER
C               B) TKH ; THERMAL CONDUCTIVITY OF HEATER
C               C) DENSH ; HEATER DENSITY
C               C) CRI ; INNER RADIUS OF CYLINDRICAL HEATER  (FT)
C               D) CRO ; OUTER RADIUS OF CYLINDRICAL HEATER  (FT)
C           1) IOHW = 3 ; FOR FUEL ROD
C               A) CPF ; SPECIFIC HEAT OF FUEL PELLET
C               B) TKH ; THERMAL CONDUCTIVITY OF FUEL PELLET
C               B) DENSH ; FUEL PELLET DENSITY
C               C) CPC ; SPECIFIC HEAT OF CLAD
C               D) TKC ; THERMAL CONDUCTIVITY OF CLAD
C               D) DENSC ; CLAD DENSITY
C               E) CRS ; RADIUS OF FUEL PELLET        (FT)
C               F) CRI ; INNER RADIUS OF CLAD         (FT)
C               G) CRO ; OUTER RADIUS OF CLAD         (FT)
C               H) GAPC ; GAP CONDUCTANCE
C
C        EXTERNAL FUNCTIONS REQUIRED......................................
C
C        HL(P,T) - LIQUID ENTHALPY
C        DENS(P,T,HL) - LIQUID DENSITY
C        HF(P) - SATURATED LIQUID ENTHALPY (BTU/LBM)
C        HFG(P) - LATENT HEAT
C        MUTL(T) -  LIQUID VISCOSITY  (LBM/HR FT)
C        COND(T) - THERMAL CONDUCTIVITY OF SATURATED LIQUID (BTU/HR-FT-F)
C        VFG(P) - SPECIFIC VOLUME OF THE GAS - SPECIFIC VOLUME OF LIQUID
C        VF (P) - SPECIFIC VOLUME OF THE SATURATED LIQUID
C        CONST(P,T) - SPECIFIC VOLUME/ENTHALPY RELATIONSHIP FOR STEAM
C        MARNEL(P,G) - PARAMETER FOR MARTINELLI-NELSON TWO-PHASE MULTIPLIER
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C      SGMA(P,T) - SURFACE TENSION OF WATER(LBF/FT)
C      ANGL(Z) - ARGUMENT OF COMPLEX Z
C      BSI0(Z) - MODIFIED BESSEL FUNCTION OF THE 1ST KIND OF ORDER ZERO
C      BSI1(Z) - MODIFIED BESSEL FUNCTION OF THE 1ST KIND OF ORDER ONE
C      BSK0(Z) - MODIFIED BESSEL FUNCTION OF THE 2ND KIND OF ORDER ZERO
C      BSK1(Z) - MODIFIED BESSEL FUNCTION OF THE 2ND KIND OF ORDER ONE
C      BER(Z) - BER FUNCTION
C      BEI(Z) - BEI FUNCTION
C      BERS(Z) - BER' FUNCTION
C      RKER(Z) - KER FUNCTION
C      RKEI(Z) - KEI FUNCTION
C      RKEIS(Z) - KEI' FUNCTION
C
       REAL KF,LAMBDA(200),K1,LR,KLOSS,MUTL,L1,L2, JOIN
       COMPLEX TAU1,TAU2,RATIO,S,Z1,Z2,Z3,M1,M2,M3,OLDRAT,TSUM2,
     1        OH,PI1,PI2,PI3,GAM1,GAM2,GAM3,ZPKP,STC2,CSTB1,CSTB2,
     2        TG,TB1,TB2,TF,TR1,TR2,HS,STC1,TEE,AAA,U1,FALF,ZPK1
       COMPLEX F11, GHPV(100), ZPK, CXJ1,CXJ2,CXJ3, CXA1,CXA2,CXA3
       COMPLEX T,SAN1,SAIN,AMN,ANM,RAIR,RAIN,SAKN,SANK,GAMN,TALP1
       COMPLEX RAN1,GANM,ZN1,BI,RKI,XZNI,XBM,XRKM,CXK,CXKN
       COMPLEX TZ1,TZ2,TWO,THREE, T1,DPHI, TGAM1,TPI1
       COMPLEX RR1,RR2,RR3, DPUP1,DPUP2,DPUP3, DWSW1,DWSW2,DWSW3
       COMPLEX TH1,TH2,TH3,PWW1,PWW2,PDWSW2,DWSW5
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
       COMPLEX GAM4,STC3,STC4,STC5,STC6,PP,TALP4,TLP4,TALP2,TALP3
     1         ,DGAMP,RR4,CLTX,ALSUM1,ALSUM2,TLP
     @         ,PI4,PM4,DWSW4,SH1,SH2,SH3,SH4
       COMPLEX PPS,CK142S,SK14S,CW,OMEGA,STOM,ZP,CSBX3
       COMPLEX CXJ4,CXA4,TCP,TLOOP4,VPL,TH4,DPUP4
       COMPLEX GPI1,GPI2,GPI3,GPI4,QL1,QL2,QL3,QL4,QL2S,QL3S,QL4S,
     @        VJ1,VJ2,VJ3,WW1,WW2,WW1S,WW2S,HIN1S,HIN2S
       COMPLEX RATIOP,RATIOK,OPTK,OPTH,OPTJ,PTOJ
       COMPLEX XK,XKP,XKRA,XKPRA,XXX,YYY,ZZZ,WWW,FFF,WTF
       COMPLEX PKJ,PKQ,PKH,PKP,PHJ1,SHJ,SHW,RATIOW,H,WH(50,2,3)
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
       DIMENSION VEL3D(200),RPWR(200),A(4,6),U(4,6),V(4,6),SV(4),
     @          WORK(4),SVMAX(50)
       DIMENSION XREA(100),YIMA(100), PER(100), AMOD(100), ARGU(100)
       DIMENSION COMM1(20),COMM2(20),COMM3(20),COMM4(20),COMM5(20),
     1     COMM6(20),COMM7(20),COMM8(20),COMM9(20),COMM10(20),
     2     COMM13(20), COMMEN(20),WW(100),AMAG(100)
       DIMENSION CPS(100), PHASE(100), VMAG(100),
     @          CLMP(50),CLDBP(50),CLAP(50),CLRP(50),CLIP(50),
     @          OPMK(50),OPDBK(50),OPAK(50),OPRK(50),OPIK(50),
     @          CLMK(50),CLDBK(50),CLAK(50),CLRK(50),CLIK(50),
     @          OPMJ(50),OPDBJ(50),OPAJ(50),OPRJ(50),OPIJ(50),
     @          CLMW(50),CLDBW(50),CLAW(50),CLRW(50),CLIW(50)
       DIMENSION TFM(2,50),TFDB(2,50),TFA(2,50),
     @          TIW(100),TFR(2,50),TFI(2,50)
C
       COMMON/OPTION/ IOSUB, IOHW, IO2Q, IPILO, ISLIP, IRW
       COMMON/CONST1/ C1(200),C2(200),C3(200),C4,C5(200),C8(200,30),
     1        C9(200,30),C18(200), C21(200), C22(200),C25(200),
     2        C26(200), I6, V7(200), DD1, CK1, CMP
       COMMON/CONST2/ P,VCH,VIN(200),AXS(200),DH(200),DHIN(200),
     1        PH(200),TIN,TSATP,ENTHI,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2        DENSF,VFG1,RHOG,G0(200),G02(200),H0(200),GC,G1,KLOSS(30),
     3        FRICMO(200),VGJH(200,30),COH(200,30),CZERO,VGJ,DPTS,
     4        G02RF(200),HFG1,ZSP(30),NUMBSP(200,30),ALHEAT,CXF(200),
     5        AVEQ,CHOMO1,CHOMO2,XKIN(200),XKEXIT(200)
C
      COMMON/CONSS1/ QDIS(200,30), QO(200,30), DZ(200,30),Z(200,30),
     1        K1(200,30), CKIN(200,30), ZETA(200,30), DOIN(200,30),
     2        DOOUT(200,30), ALPIN(200,30),BEE(200,30), CPI1(200,30),
     3        COR2PH(200,30), ZETSP(200,30), WIN
      COMMON/PCHOUT/XCHOUT(200), ACHOUT(200), CCHOUT(200)
      COMMON /DIM1/ DELX, DELZ, CHLAMB(200), ALFNOD(200,30),
     1                DBLAMB(200)
      COMMON/VSOS/VOL
      COMMON/CONSS2/ NTOT(200),NBB(200),NBB1(200),NSP,N1PSP(200),
     1                K2PSP(200), NDP(200), NDP1(200), ISUB(200)
      COMMON /PERI/ DELVI, DELQO, DELK,DELP
      COMMON /CONWD1/ CPH,TKH,DENSH,CPC,TKC,DENSC,CRS,CRI,CRO,
     1                 GAPC, V22(200,30), THICKH
C
      COMMON /RISER/ COR,VGJR,CKRO,RL,AR,DRIN,DR,PI,CL1,CL2,CL3,CL4,
     1        CL5, CL6, CR5, CR6, UPJ1(200), UPJ2(200), RO11, RO12,
     2                RO21, RO22, XROUT, UPJIN
      COMMON /CLOOP/ SLOOP, SFLOOP, RLOOP,AA,
     @                VL1(200), VL2(200), VL3(200), DPLPT,RATW
      COMMON /CUPPER/RKIN,RKEXIT,AP,RPO,RP1,RP2,CL10(200),CL11(200),
     1                 CLT,AXSCH,RAR,AD,DL,DHDL,FDL, F1(200),F2(200),
     2                 RJ1(200),RJ2(200),RJ3(200),F3(200)
      COMMON /CDELH1/ HFW, ADC, PHV, DKV, CPV, DENV, TEMV, TEMINV,
     1                 THV, HOD, PLM, AHLP, THLP, HOLP, WO, DLENG
      COMMON /CDELH2/ CH1, CH2, CH3, CH4, CH5, CH7, CH8, CH9, CH10
      COMMON /CGHT/ F11
      COMMON /RESULT/XZ, SS1, SS2
      COMMON/SIM1/IMAX,JMAX,KMAX,ICASE,ISPEC,JSPEC,INUCLR,XKEFF
      COMMON/SIM2/JMX(20),NFT(15,15,30),AL(15,15),TAL(15,15),
     1             BAL(15,15),ASRC(15,15),SRC(15,15,30),AEXP(15,15),
     2             REXP(15,15,30),AXSRC(30),XXSRC(30)
      COMMON/SIM3/JJD(15,15),DZ1(200),DZ2(200),NF(200,30),ND(200),
     1             SCCC(200,30,6),XEXP(200,30),SIG1(200,30,11),
     2             CSIG1(200,30,11)
      COMMON/SIM4/TEE(15,15,30)
      COMMON/SIM5/RXA(15,15),RXF(15,15),RV(15,15),RCXF(15,15),
     1             RCXA(15,15),RCV(15,15)
      COMMON/SIM6/RHOX(15,15,30),RHOZ(15,15,30),RX(15,15,30),
     1 [illegible](15,15,30),TEEO(15,15,30),PLAMDA(6),FPET(35),FPLAN(15)
      COMMON/KIN1/XKINF(15,15,30),SIGF(15,15,30)
      COMMON/KIN2/RRDF(15,15),RRCDF(15,15),RANOI(200,4),ADF(30),
     1             ACDF(30),GANOM(200,30,6),CFP
      COMMON/KIN3/RANI(200,4),GANM(200,30,6),ZNI(200,4),BI(200)
      COMMON/KIN5/RKI(200),XZNI(200,30,6),XBM(200,30),XRKM(200,30)
      COMMON/PTKO/ZPK, ZPK1, ZPKP,DRDU, VOCAL
      COMMON/PTK1/AAA(200)
      COMMON/COEF1/WA(10,2,11),WB(10,2,11),WC(10,2,11),WD(10,2,11),
     1              WE(10,2,11),WF(10,2,11),WG(10,2,11),WHP(10,2,11),
     2              WI(10,2,11),WJ(10,2,11),WK(10,2,11)
      COMMON/COEF2/D1,D2,D3,D4,D5,D6,D7,D8,D9,D10,D11,D12,SUMSRC
      COMMON/COEF3/NFTMX
      COMMON/XX/T(200,30,6),SANI(6),SAIN(6),AMN(6),ANM(6),RAIR(200),
     1           RATN(200,4),SAKN(2),SANK(2),GAMN(200,30,6)
      COMMON/VOIDPT/FALF(200,30),U1(200),TGAM1(200),TPI1(200)
      COMMON/TWOG1/SIG2(200,30,11),CSIG2(200,30,11),TFLX(2,4,30)
      COMMON/TWOG2/PWH1(100,100),PWH2(100,100),TZ1(100,100),
     1              TZ2(100,100),TWO(100,100),THREE(100,100)
      COMMON/TEST/CXK(15,15,30), CXKN(200,30,6)
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C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMMON/SKIN/XK(5,30,5,30),XKP(5,30),XKRA(10,10),XKPRA(10)
      COMMON/GKIN/,KIN,IDCHTY(15,15),ITY(225),JJMX(15),JJDB(15,15),
     @              ITY8(150)
      COMMON/DELTAP/DGAMP,DRHOG,DHF,DHG,DCZERO,DVGJ,DCOR,DVGJR
      COMMON/RISERP/CLTX,RR4,CRP5,CRP8,RO13,RO23,CL12,UPJ3,ALPRO,
     1               GOR,RHOR,VRO,CRCON,UPALP
      COMMON/SWITCH/IDCZC,IDVGJC,IDCZR,IDVGJR
      COMMON/PSP/CSBX3(200,30),ALOUT(200,30)
      COMMON/PXX/PXEXT(200,30)
      COMMON/YYY/ZLUP,FLUP,GOU,DHUP,ROUP,FUP,ZLR,FLR,ROR,FRR
     @           ,ADLP,DHLP,ZLLP,FLLP,XKLP,GOLP,FLP
     @           ,AD1,DH1,ZL1,FL1,XK1,GO1,FD1
     @           ,AD2,DH2,ZL2,FL2,XK2,GOD2,FD2
     @           ,AD3,DH3,ZL3,FL3,XK3,GO3,FD3
     @           ,SPUMP,CPUMP
      COMMON/SEPA/XINER,XLSEP,XKSEP,XASEP,XRHOS,ALPSEP,
     @            GOSEP,YLSEP,DHSEP,FSEP,CSEP,VSEP,CORPR
      COMMON/POINIK/PKJ,PKQ,PKH,PKP,PHJ1,SHJ,SHW
      COMMON/PIV/IV
      COMMON/PGAM/IGAM,IDRF
      COMMON/QQQ/Q3D(200,30)
      COMMON/PCO/ICO
      COMMON/RNEW/F3P,RJ3P
      COMMON/PWF/PWFIN(10),PWINT(10),PWMULT(10)
      COMMON/MULT/NN(200)
      COMMON/MULTW/UPJW(200),CLW(200),PJOUT(200)
      COMMON/SSS/GPI1(5),GPI2(5,30),GPI3(5),GPI4(5),
     @QL1(5),QL2(5,30),QL3,QL4,QL2S(5,30),QL3S(5),QL4S(5),
     @   VJ1(5),VJ2(5),VJ3(5),WW1(5),WW2,WW1S(5,5),
     @           WW2S(5),HIN1S(5),HIN2S
      COMMON/VEL/VELD(200)
      COMMON/TF/RATIOP,RATIOK,OPTK,OPTH,RATIOW,OPTJ,PTOJ
      COMMON/MIMO/H(2,3)
      COMMON/PBB/POWER,BYPOWF,BYFLWF
C   QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C     ********   FORMAT   ******************************
C
    1 FORMAT(20A4)
    2 FORMAT(8I4)
    3 FORMAT(8F10.4)
    4 FORMAT(6E10.4)
    5 FORMAT(2E12.6)
    6 FORMAT(2E15.5)
    7 FORMAT(///10X,'*****   POWER-TO-VOID TRANSFER FUNCTION   *****')
    8 FORMAT(///10X, '@@@  OPEN-LOOP TRANSFER FUNCTION AT  Z = ',
     1        2X,F8.2 ,2X,'@@@' )
    9 FORMAT(/12X,'CPS',17X, 'GH',22X,'MAG',18X,'PHASE')
   10 FORMAT(1H0, 43H***** EXIT QUALITY OUTSIDE LIMITS, XEXIT =  , F6.2)
   12 FORMAT(/// 46H **** NO FORCING FUNCTION WAS SPECIFIED *****'       )
   13 FORMAT(8X,F9.5,3X,2(2X,E10.4),5X,E10.4,5X,E10.4)
   15 FORMAT(///,32X, 'NYQUIST PLOT' //
     1 11X,'PERIOD',19X,4HREAL,10X,4HIMAG,9X,'MODULE',8X,'ARG' //
     2       (I6, F11.4, 12X, 3E14.3, F11.4 ))
   16 FORMAT(///,1H1, 50X, 16HNYQUIST DIAGRAM     )
   17 FORMAT(///15X,'STABILITY MARGIN',/15X,'MAGNITUDE  =',F9.4,
     1       ' (DB)',/15X,'PHASE  =',4X,F9.4,' (DEGREE)')
   18 FORMAT(1X,'STABILITY MARGIN'/,F10.4,' (DB)')
   19 FORMAT(2X,'ICASE = ',I3)
   20 FORMAT(///15X,'*** SYSTEM IS UNSTABLE ***')
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  202 FORMAT(///15X,'*** OR STABILITY MARGINS IS NOT CALCULATED ***'
   @    /,15X,'*** DUE TO INADEQUATE FREQUENCY POINTS ***')
   21 FORMAT(10X,'**RATIO = **',2(5X,E12.6))
   31 FORMAT(1H1, 25X, 20A4 //)
   33 FORMAT(1H1,//////5X,'***** SINGLE NODE ANALYSIS *****')
   34 FORMAT(//1X, 18HSYSTEM PARAMETERS    //
     1       5X,30H P = SYSTEM PRESSURE (PSIA) = , F9.2  /
     2       5X,35H TIN = INLET TEMPERATURE (DEG-F) = , F9.2 /
     3       5X, 'SATURATION TEMPERATURE CORRESPONDING TO P (F) = '
     4       , F9.2 /
     5       5X,'ACTIVE FUEL (HEATER) LENGTH (FT) = ', F9.4/
     6       5X,'CORE AVERAGE VOLUMETRIC HEAT  =',E12.6//
     7       5X,'TOTAL NUMBER OF CHANNELS  = ',I5/
     8       5X,'TOTAL NUMBER OF NODES IN CHANNEL = ', I4)
   35 FORMAT(//,'FREQUENCY',/5X,'INITIAL FREQ.  =',F9.6/
     1    5X,'FINAL FREQ.     =',F9.6/5X,'FREQ. INTERVAL  =',F9.6)
   36 FORMAT(//,'OPTION', /5X,'IOSUB  =',I4/5X,'IOHW  =',I4/
     1      5X,'IO2Q  =', I4/5X,'IK  =',I4/5X,'ISI  =',I4/
     2      5X,'IREG =', I4/5X,'IBODE=',I4)
   37 FORMAT(///,'EXTERNAL PERTURBATION')
   38 FORMAT(/5X,'** DELVI   =  ',F9.3, '**' )
   39 FORMAT(/5X,'** DELQO   =  ',F9.3, '**' )
   41 FORMAT(/5X,'** DELDP   =  ',F9.3, '**' )
   42 FORMAT(/5X,'** DELK    =  ',F9.3, '**' )
   54 FORMAT(//13X, '**  THE B.B. OF CORE-AVERAGED CHANNEL  =',
     1       2X,F12.6,2X, '(FT)  **')
   60 FORMAT(/// 46H **** NO FORCING FUNCTION WAS SPECIFIED *****
   61 FORMAT(/10X, '**********  NODE-AVERAGED VOID FRACTION',
     1       2X,'**********')
   62 FORMAT(/15X, 6(5X,E10.4) )
   63 FORMAT(//10X, 'NODE   =',3X,I3)
   64 FORMAT(////1H1 FREQUENCY=,E10.3,5HRAD/S,10X,7HPERIOD=,E10.3,3HSEC,
     1      5X, 8H(MULT.= , F7.4, 1H), 1H0)
   65 FORMAT(/5X,'FREQUENCY',5X,'MAGNITUTE')
   66 FORMAT(/5X,'FREQUENCY',9X,'PHASE')
   70 FORMAT(//10X, '**** ITERATION FOR FLOW REDISTRIBUTION DIVERGE'
     1             ,' ****',/15X,'PRESS. DROP ITERATION =',I4,
     2             /15X,'FLOW RATE ITERATION =',I4)
   71 FORMAT(//3X, '3) PRESSURE DROP ACROSS THE CORE  =', 2X,F10.4,
     1       //3X, '4) PRESSURE DROP IN THE LOOP   =', 2X,F10.4,
     2       //3X, 'TOTAL PRESSURE DROP IN THE WHOLE LOOP',
     3       ' (PUMP HEAD)  =', 2X,F10.4 )
C
C    ********   INPUT    ****************************
      READ(5,1) COMMEN
C
      READ(5,1) COMM1
      READ(5,1) COMM9
      READ(5,2) ICASE, ISPEC, JSPEC, IRUN, ICAL
      IF(IRUN .EQ. 0) GO TO 2000
C
      READ(5,2) NCH, NODES, NSP
C    * OPTION
      READ(5,1) COMM2
      READ(5,2) IOSUB, IOHW, IO2Q, IK, ISI, IREG, IBODE, IPRINT
      READ(5,2) IPILO, ISLIP, IRW
C    * POWER, BYPOWF, BYFLWF
      READ(5,1) COMM8
      READ(5,4)POWER,BYPOWF,BYFLWF
C    * SYSTEM(CORE) PARAMETER
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      READ(5,1) COMM3
      READ(5,4) P, TIN, ALHEAT, TSATP, AVEQ
C     * PARAMETERS FOR FLOW REDISTRIBUTION
      IF(IRW .EQ. 0) GO TO 100
      READ(5,4) DPGS, WIN
C     * CHANNEL COMMON PARAMETERS
  100 READ(5,1) COMM5
      READ(5,4) CZERO, VGJ, DELX, DELZ, CHOMO1, CHOMO2
      READ(5,4) CKI, CMP
C     * LOCAL LOSS COEFFICIENT
      IF(NSP .EQ. 0)GO TO 3333
      READ(5,1) COMM10
      DO 101 N=1,NSP
      READ(5,5) ZSP(N), KLOSS(N)
  101 CONTINUE
C
 3333 IF(ICAL .LE. 1) GO TO 110
      IF(ICAL .EQ. 4) GO TO 110
C
C     * FOR THE LOOP ANALYSIS
C
C       1) FOR THE UPPER PENUM
      READ(5,1) COMM13
      READ(5,4) AXSCH, AP, RAR, RPO, RP1, RP2
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      READ(5,3) ZLUP,FLUP
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C       2) RISER
      READ(5,1) COMM13
      READ(5,4) COR, VGJR, RL, AR, DRIN, RKIN, RKEXIT
      READ(5,3) ZLR,FLR
C       3) STEAM SEPARATOR
      READ(5,1)COMM13
      READ(5,3)XINER,XLSEP,XKSEP,XASEP,YLSEP,DHSEP,CSEP
C       4) STEAM DOME
      READ(5,1)COMM13
      READ(5,4)ADOME,VDOME,TURB
C       5) LOOP
      READ(5,1) COMM13
      READ(5,4) SLOOP, SFLOOP, AA, AD, DL, CHDL, WO, RATW
C
      IF(ICAL .NE. 3) GO TO 110
C
C       6) DOWNCOMER
      READ(5,1) COMM13
      READ(5,4) HFW, ADC, PHV, DKV, CPV, DENV, TEMV, TEMINV, THV,
     1               HOD, DLENG
C
      HOD=HOD/3600.
C       7) LOWER PLENUM
      READ(5,1) COMM13
      READ(5,4) PLM, AHLP, THLP, HOLP
  110 READ(5,3) ADLP,DHLP,ZLLP,FLLP,XKLP
C       8) DOWNCOMER D1
      READ(5,3) AD1,DH1,ZL1,FL1,XK1
C       9) DOWNCOMER D2
      READ(5,3) AD2,DH2,ZL2,FL2,XK2
C      10) DOWNCOMER D3
      READ(5,3) AD3,DH3,ZL3,FL3,XK3
C      11) JET PUMP
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      READ(5,333) IPUMP,SPUMP
  333 FORMAT(I4,F10.0)
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      HOLP=HOLP/3600.
      AVEQ=AVEQ/3600.
      WO=WO*1.0E+06/3600.
      IF(IRW .EQ. 0)GO TO 102
      WIN=WIN*1.0E+06/3600.
  102 CONTINUE
      NCH1 =  1
      KMAX=NODES
C
C     * READ 3D NUCLEAR INPUT DATA
C
      CALL NUCLER
C
C     * CHANNEL PARAMETRS
      READ(5,1) COMM4
      JLL=1
      READ(5,2)JRR
      JR=JRR
      DO 121 J=JLL,JRR
      READ(5,2)NN(J)
      READ(5,4) VEL3D(J),PH(J),AXS(J),DHIN(J),CXF(J),XKIN(J),
     1          XKEXIT(J),RPWR(J)
        READ(5,1) COMM4
        KNOD = 0
  122   KNOD1 = KNOD + 1
        KNOD5 = KNOD + 5
        READ(5,4) (Q3D(J,I), I=KNOD1,KNOD5)
        KNOD = KNOD + 5
      IF(KNOD .LT. NODES) GO TO 122
  121 CONTINUE
C     * PERTURBATION PARAMETER & FREQUNCY
      READ(5,1) COMM6
      READ(5,4) DELVI,DELQO,DELK,DELP
      IF(DELP .EQ. 0.)GO TO 11
C  PPPPPPPPPPPPPPPPPP?PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP?PP
C  READ IN SWITCHES; 1=USE DERIVATIVE, 0=NOT USED
      READ(5,2) IDCZC, IDVGJC, IDCZR, IDVGJR
      READ(5,2) IDRHOG, IDHF, IDHG
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
   11 CONTINUE
      READ(5,40)IWC
   40 FORMAT(I4)
      READ(5,44)(PWFIN(I),PWINT(I),PWMULT(I),I=1,IWC)
   44 FORMAT(3F10.0)
C     * PARAMETERS FOR HEATED WALL DYNAMICS
      READ(5,1) COMM7
      IF(IOHW .EQ. 1) GO TO 130
      IF(IOHW .EQ. 2) GO TO 131
      IF(IOHW .EQ. 3) GO TO 132
      IF(IOHW .EQ. 4) GO TO 133
  130 READ(5,4) CPH, DENSH
      GO TO 134
  131 READ(5,4) CPH, TKH, DENSH, THICKH
      GO TO 134
  132 READ(5,4) CPH, TKH, DENSH, CRI, CRO
      GO TO 134
  133 READ(5,4) CPH,TKH,DENSH, CPC,TKC,DENSC, CRS,CRI,CRO, GAPC
      GAPC=GAPC/3600.
  134 CONTINUE
      IF(IK .EQ. 0)GO TO 991
C
C
      IF(ICASE.EQ.13.OR.ICASE.EQ.14.OR.ICASE.EQ.15) GO TO 140
      GO TO 150
  140 CONTINUE
      JRMAX=JMX(IMAX)
      NCHQ=JJD(IMAX,JRMAX)
      DO 160 N=1,NCHQ
      READ(5,3) (TFLX(1,N,K9),K9=1,KMAX)
  160 READ(5,3) (TFLX(2,N,K10),K10=1,KMAX)
  150 CONTINUE
C
      IF(ICASE.EQ.5.OR.ICASE.EQ.7.OR.ICASE.EQ.9) GO TO 200
C
      GO TO 220
  200 CONTINUE
      SUMSRC=0.
      MSPEC=JJD(ISPEC,JSPEC)
      DO 730 K=1,KMAX
  730 SUMSRC=SUMSRC+SRC(ISPEC,JSPEC,K)/FLOAT(KMAX)
      DO 740 K=1,KMAX
      SRC(ISPEC,JSPEC,K)=SRC(ISPEC,JSPEC,K)/SUMSRC
  740 CONTINUE
  220 CONTINUE
C
C     * NUCLEAR CROSS-SECTION MODELING
C
      CALL XSMODL
C
C   **************    PRINT   INPUT   PARAMETER   **********************
C
  991 CONTINUE
      WRITE(6,31) COMMEN
      READ(5,49)ICE,CKCAAL,IV,ICVGJ,IKEY,IDRF,XWK,XWM
   49 FORMAT(I4,F10.3,I4,I4,I4,I4,2F10.5)
      READ(5,2)ICO,ISOS,IW,IPX,IENT,IRSLIP
      READ(5,48)IVOCAL,PCAPLA,DOP
   48 FORMAT(I4,2F10.0)
      IF(IK .EQ. 0)GO TO 1663
      READ(5,166)IMAX
      READ(5,166)(JMX(I),I=1,IMAX)
      READ(5,166)(JJMX(I),I=1,IMAX)
      DO 165 IR=1,IMAX
      JRX=JMX(IR)
      READ(5,166)(IDCHTY(IR,JC),JC=1,JRX)
  165 CONTINUE
  166 FORMAT(15I3)
      ID=0
      DO 45 I=1,IMAX
      JR=JMX(I)
      DO 46 J=1,JR
      JJD(I,J)=ID+J
   46 CONTINUE
      ID=JJD(I,JR)
   45 CONTINUE
      DO 1661 IR=1,IMAX
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315

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      JRX=JMX(IR)
      DO 167 J=1,JRX
      M=JJD(IR,J)
      ITY(M)=IDCHTY(IR,J)
  167 CONTINUE
 1661 CONTINUE
      IF(ICASE .EQ. 1)GO TO 1662
      ID=0
      DO 168 IR=1,IMAX
      JRX=JJMX(IR)
      DO 169 J=1,JRX
  169 JJD8(IR,J)=ID+J
      ID=JJD8(IR,JRX)
  168 CONTINUE
      DO 171 IR=1,IMAX
      JRX=JJMX(IR)
      DO 172 J=1,JRX
      M=JJD8(IR,J)
  172 ITY8(M)=IDCHTY(IR,J)
  171 CONTINUE
 1662 CONTINUE
      WRITE(6,499)IV,ICVGJ,IKEY,IDRF,XWK,XWM
  499 FORMAT('LOOP OPTION IV= ',I2,2X,'ICVGJ = ',
     @ I2,2X,'IKEY= ',I2,2X,'IDRF= ',I2,2X,'XWK,XWM= ',2(F10.5,2X))
      WRITE(6,151)ICO,ISOS,IW,IPX,IENT,IRSLIP,IVOCAL
  151 FORMAT('ICO= ',I2,2X,'ISOS= ',I2,2X,'IW=',I2,2X,'IPX=',I2,2X,
     @        'IENT=',I2,2X,'IRSLIP= ',I2,2X,'IVOCAL= ',I2)
      WRITE(6,173)PCAPLA,DOP
  173 FORMAT('NEUTRON LIFETIME(SEC)= ',E10.4,5X,
     @        'DOPPLER COEFF.= ',E10.4)
      WRITE(6,175)POWER,BYPOWF,BYFLWF
  175 FORMAT(//,'POWER = ',E10.4,' MWT',/2X,
     @        'BYPASS POWER FRACTION = ',E10.4,2X,
     @        'BYPASS FLOW FRACTION= ',E10.4)
      IF(ICASE .EQ. 1)GO TO 1663
      WRITE(6,176)
  176 FORMAT('CHANNEL TYPE MAP IMAX JMX STRUCTURE 2D IDCHTY OPTION')
      DO 1165 IR=1,IMAX
      JRX=JMX(IR)
 1165 WRITE(6,166)(IDCHTY(IR,J),J=1,JRX)
      MJMAX=JMX(IMAX)
      MMAX=JJD(IMAX,MJMAX)
      WRITE(6,177)
      WRITE(6,166)(ITY(M),M=1,MMAX)
  177 FORMAT('CHANNEL TYPE MAP.IMAX JMX STRUCTURE 1D ITY OPTION')
      WRITE(6,178)
  178 FORMAT('CHANNEL TYPE MAP IMAX JJMX STRUCTURE 2D OPTION')
      DO 1168 IR=1,IMAX
      JJRX=JJMX(IR)
      WRITE(6,166)(IDCHTY(IR,J),J=1,JJRX)
 1168 CONT'NUE
      MJJMAX=JJMX(IMAX)
      MMAXJ=JJD8(IMAX,MJJMAX)
      WRITE(6,179)
  179 FORMAT('CHANNEL TYPE MAP IMAX JJMX STRUCTURE 1D ITY8 OPTION')
      WRITE(6,166)(ITY8(M),M=1,MMAXJ)
 1663 CONTINUE
      POWER=POWER*1.0E+06*3.4137/3600.
C
      IF(NODES .EQ. 1) WRITE(6,33)
      WRITE(6,34) P, TIN, ISATP, ALHEAT, AVEQ, NCH, NODES
      WRITE(6,36) IOSUB, IOIW, IO2Q, IK, ISI, IREG, IBODE
C
      WRITE(6,37)
      IF((DELVI+DELQO+DELK+DELP) .LE. 0.0) GO TO 6000
      IF(DELVI .NE. 0.) WRITE(6,38) DELVI
      IF(DELQO .NE. 0.) WRITE(6,39) DELQO
      IF(DELK .NE. 0.) WRITE(6,42) DELK
      IF(DELP .NE. 0.) WRITE(6,41) DELP
C
      G1 = 32.17
      GC = 32.17*144.
      PI = 3.141592654
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C J=778.158 LBF-FT/BTU
      PJ=778.158/144.
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      IWIT = 0
      KIP1 = 0
      KIP2 = 0
      MSPEC = 0
      SUMA=0.
      EPS1 = 1.0E-02
      IF(IRW .EQ. 0)GO TO 95
      EPS2 = WIN*1.0E-02
   95 CONTINUE
  301 DO 340 I=JLL,JRR
  300 VCH = VEL3D(I)
      DO 315 J=1,NODES
      DZ(I,J) = DELZ
      QDIS(I,J) = Q3D(I,J) * AVEQ*RPWR(I)
  315 CONTINUE
      ICH = 0
      IF(IRW .EQ. 0) GO TO 316
      IF(IRW .EQ. 1 .AND. IWIT .LE. 1) GO TO 325
  316 ICH = IPRINT
C
C     * CALCULATE CONSTANTS WHICH ARE INDEP'T ON NODES
C
  325 CALL CONSS(I,ICH,ICAL,IWIT)
      IF(ISLIP .EQ. 0 .AND. ICVGJ .NE. 0)GO TO 311
      GO TO 411
  311 CZERO=1.2-0.2*SQRT(RHOG/DENSF)
      TAVE=(TIN+TSATP)/2.
      SIGMA=SGMA(P,TAVE)
      VGJ=2.9*(C4*SIGMA*G1*32.2/DENSF**2)**0.25
  411 CONTINUE
      IF(DELP .EQ. 0.)GO TO 412
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C IF SWITCH IS OFF SET DERIVITE TO ZERO
      IF(IDRHOG .EQ. 0)DRHOG=0.0
      IF(IDHF.EQ. 0) DHF=0.0
      IF (IDHG .EQ. 0)DHG=0.0
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
C     * CALCULATE STEADY-STATE NODE QUANTITIES & PRESSURE DROPS
C
C
  412 CALL STEADY(NODES, I, ICH, ICAL, IWIT,CHALF,RPWR)
```

```
      IF(IRW .EQ. 0)SUMA=SUMA+CHALF*NN(I)
      IF(IWIT .LT. 2)GO TO 53
      SUMA=SUMA+CHALF*NN(I)
   53 CONTINUE
C
C      * FLOW REDISTRIBUTION WITH CONSTANT PRESSURE DROP B.C. FOR
C          EACH CHANNEL
C        DPTS ; CALCULATED TOTAL PRESSURE DROP IN THE CHANNEL
C        DPGS ; EXPECTED CONSTANT PRESSURE DROP THROUGH ALL CHANNEL
C        EPS1 ; CONVERGENCE CRITERION
C
       IF(IRW .EQ. 0) GO TO 335
       IF(IWIT .EQ. 2) GO TO 335
      RDPCH = (DPTS-DPGS) / DPGS
       IF(ABS(RDPCH) .LE. EPS1) GO TO 330
       VEE = DPGS/DPTS
       VEL3D(I) = SQRT(VEE)*VEL3D(I)
       WRITE(6,82)I,KIP1,DPGS,DPTS,VEL3D(I)
   82  FORMAT(//'CHANNEL TYPE,KIP1,DPGS,DPTS,VIN',2X,I2,2X,I4,2X,
     @         3(E13.6,2X))
       KIP1 = KIP1 + 1
       IF(KIP1 .GT. 30) GO TO 4000
       IWIT = 1
       GO TO 300
C
  330  IWIT = 0
       KIP1 = 0
       GO TO 340
  335 IF((XCHOUT(I).GT.1.0) .OR. (XCHOUT(I).LE.0.0)) GO TO 5000
  340 CONTINUE
      VFCORE=SUMA/FLOAT(NCH)
C
C      * APPLY ANOTHER B.C ; WIN = SUM OF WI
C         WIN ; CORE TOTAL INLET FLOW RATEEXCLUDING BYPASS FLOW
C         WI  ; CHANNEL INLET FLOW RATE
       IF(IRW .EQ. 0) GO TO 355
       IF(IWIT .EQ. 2) GO TO 355
       WSUM = 0.
       DO 345 J=JLL,JRR
       WSUM = WSUM + VIN(J)*AXS(J)*DENSI*NN(J)
  345  CONTINUE
       IF(ABS(WIN-WSUM) .LE. EPS2) GO TO 350
       DPGS = DPGS*(1.+(SQRT(WIN)-SQRT(WSUM))/SQRT(WIN))
       WRITE(6,84)KIP2,DPGS,DPTS,(VIN(I),I=JLL,JRR),WSUM
   84  FORMAT('KIP2,DPGS,DPTS,VIN,WSUM',2X,I4,2X,8(E13.6,2X))
       KIP2 = KIP2 + 1
       IF(KIP2 .GT. 30) GO TO 4000
       GO TO 301
  350  IWIT = 2
       GO TO 301
C
  355 DO 370 J=JLL,JRR
      IF(ISUB(J) .GT. 0) GO TO 360
      LAMBDA(J) = CHLAMB(J)
      GO TO 370
  360 LAMBDA(J) = 0.
  370 CONTINUE
      DO 426 I=JLL,JRR
      VELD(I)=VEL3D(I)
  426 CONTINUE
```

```
C
C
      JL1=JLL
      JR1=JR
C
C     * CALCULATE THE S.S PARAMETERS OF THE LOOP
C
      DPLPT = 0.
      IF(IRW .EQ. 1) GO TO 393
      WOSUM = 0.
      DO 392 I=JLL,JRR
      WOSUM = WOSUM + AXS(I)*GO(I)*NN(I)
  392 CONTINUE
      WIN = WOSUM
      DPGS = DPTS
  393 IF(ICAL .LE. 1) GO TO 391
      CALL XLOOP(ICAL, JLL, JRR,IPUMP,IRSLIP)
  391 CONTINUE
      IF(IK .EQ. 0) GO TO 400
C
C     * GENERATE 3D CROSS-SECTION AS FUNCTIONS OF VOID & EXPOSURE
C
      CALL XDATA
C
C
C
C    $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C     . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C     *  CALCULATE EACH PERTURBATION CORRESPONDING TO FREQUENCY
C     . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C
  400 CONTINUE
      IF(ICAL.EQ.0) GO TO 2000
      IX=0
      IY=0
      ICOUNT = 1
      IF(IREG .GE. 1) ICOUNT = 0
   55 IX=IX+1
      IF(IX .GT. IWC)GO TO 600
      WMULT=PWMULT(IX)
      WINT=PWINT(IX)
      WFIN=PWFIN(IX)
      IF(WINT .GT. WFIN)GO TO 600
      WMUL=WMULT
      ISIG=ISI-1
      SIG = 10.0**(-ISI)
      SIGP1 = 1.0 + SIG
      OLDW=0.0
      RATIO = CMPLX(0.,0.)
C
      W1=WINT
      OLDW = 100000.0
      GO TO 415
  410 CONTINUE
      IF(IREG.EQ.2) W1=W1+WMUL
      IF(IREG.NE.2) W1=W1*WMUL
  415 IF(W1.GT.WFIN .AND. IX .LE. IWC)GO TO 55
      PERIOD = 2.0*PI/W1
      IF(IREG .GE. 1) GO TO 420
      OLDRAT = RATIO
      NPER=INT(ALOG10(PERIOD))
      IF(PERIOD.LE.1.0)ISIG=ISI
      PERIOD=AINT(10.**ISIG*PERIOD/(10.**NPER))*10.**(NPER-ISIG)
      W1 = 2.0*PI/PERIOD
      IF(ABS(OLDW-W1)/OLDW.LE.10.0**(-ISI)) GO TO 410
  420 S=CMPLX(0.,W1)
      IF(IREG .GE. 1) GO TO 425
      IF(OLDW .GT. W1)  GO TO 430
  425 ICOUNT = ICOUNT + 1
      IY=IY+1
      IF(ICOUNT .GT. 100) GO TO 600
  430 IF(ICASE .EQ. 999 .OR. DELP .NE. 0)GO TO 431
      WRITE(6,64)W1,PERIOD, WMUL, ICOUNT
  431 CONTINUE
      WW(ICOUNT)=W1
      IF(ICAL .GE. 4) GO TO 600
C
C
C    ***   CALCULATE NEUTRON KINETICS TRANSFER FUNCTION   ***
C
      ZPK = CMPLX(0.0,0.0)
      ZPKP= CMPLX(0.0,0.0)
C
C
      IF(ICASE.EQ.13.OR.ICASE.EQ.14.OR.ICASE.EQ.15) GO TO 475
      CALL COEFT(S, ICOUNT)
  475 CALL KINET(S,ICOUNT,DELK,DELP,IVOCAL,CKCAAL)
      VOCAL=DRDU
      IF(ICASE .NE. 1)GO TO 473
      ZPK=ZPK/AVEQ
      ZPK1=ZPK1/AVEQ
  473 CONTINUE
   58 FORMAT(8(E13.6,1X))
C     REQUEST FILE 99 (THERMAL HYDRAULIC TRANSFER FUNCTIONS)
  480 CONTINUE
      READ(99,58)PKJ,PKQ,PKH,PKP,PHJ1,SHJ,SHW
C
      READ(99,58)(U1(ICHL),ICHL=JLL,JRR)
      DO 182 ICHL=JLL,JRR
  182 READ(99,58)(FALF(ICHL,K),K=1,KMAX)
      READ(99,58)(XKPRA(ICHL),ICHL=JLL,JRR)
      DO 184 ICHL=JLL,JRR
  184 READ(99,58)(XKP(ICHL,K),K=1,KMAX)
      DO 186 ICHL1=JLL,JRR
  186 READ(99,58)(XKRA(ICHL1,ICHL2),ICHL2=JLL,JRR)
      DO 188 IC1=JLL,JRR
      DO 190 JK1=1,KMAX
      READ(99,58)((XK(IC1,JK1,IC2,JK2),JK2=1,KMAX),IC2=JLL,JRR)
  190 CONTINUE
  188 CONTINUE
  487 CONTINUE
      CALL PTRANS(S,IK,RATIO,AMRAT,ARRAT,NCH1,ICOUNT,IBODE,IW,
     @            JLL,JRR,ICASE)
      TFW(IY)=AIMAG(S)
      DO 195 IA=1,2
      IF(IA .EQ. 1)WTF=RATIOP
      IF(IA .EQ. 2)WTF=RATIO
      TFM(IA,IY)=CABS(WTF)
      XM=TFM(IA,IY)
      IF(IA .EQ. 1)TFM(IA,IY)=TFM(IA,IY)*100.
      TFDB(IA,IY)=20.*ALOG10(XM)
      TFA(IA,IY)=ANGL(WTF)
      TFR(IA,IY)=REAL(WTF)
      TFI(IA,IY)=AIMAG(WTF)
  195 CONTINUE
      IF(ICASE .NE. 1)GO TO 505
      CLMP(IY)=CABS(RATIOP)*100.
      XLMP=CABS(RATIOP)
      CLDBP(IY)=20.*ALOG10(XLMP)
      CLAP(IY)=ANGL(RATIOP)
      CLRP(IY)=REAL(RATIOP)
      CLIP(IY)=AIMAG(RATIOP)
      CLMK(IY)=CABS(RATIOK)
      XLMK=CABS(RATIOK)
      CLDBK(IY)=20.*ALOG10(XLMK)
      CLAK(IY)=ANGL(RATIOK)
      CLRK(IY)=REAL(RATIOK)
      CLIK(IY)=AIMAG(RATIOK)
      OPMK(IY)=CABS(OPTK)
      OPDBK(IY)=20.*ALOG10(OPMK(IY))
      OPAK(IY)=ANGL(OPTK)
      OPRK(IY)=REAL(OPTK)
      OPIK(IY)=AIMAG(OPTK)
      CLMW(IY)=CABS(RATIOW)
      XLMW=CABS(RATIOW)
      CLDBW(IY)=20.*ALOG10(XLMW)
      CLAW(IY)=ANGL(RATIOW)
      CLRW(IY)=REAL(RATIOW)
      CLIW(IY)=AIMAG(RATIOW)
      OPMJ(IY)=CABS(OPTJ)
      OPDBJ(IY)=20.*ALOG10(OPMJ(IY))
      OPAJ(IY)=ANGL(OPTJ)
      OPRJ(IY)=REAL(OPTJ)
      OPIJ(IY)=AIMAG(OPTJ)
      DO 852 I1=1,2
      DO 854 I2=1,3
      WH(IY,I1,I2)=H(I1,I2)
  854 CONTINUE
  852 CONTINUE
  505 CONTINUE
      IF(ICASE .EQ. 1 .AND. IBODE .EQ. 0)RATIO=OPTK
      IF(ICASE .EQ. 1 .AND. IBODE .EQ. 0 .AND. DELVI .NE. 0)RATIO=
     @                                                          OPTJ
      IF(IBODE .NE. 0) GO TO 481
      PER(ICOUNT) = PERIOD
      XREA (ICOUNT) = REAL(RATIO)
      YIMA (ICOUNT) = AIMAG(RATIO)
      AMRAT=CABS(RATIO)
      AMOD(ICOUNT) = AMRAT
      AMRAT=20.*ALOG10(AMRAT)
      ARRAT=ANGL(RATIO)
      ARGU(ICOUNT) = ARRAT
      HWA1=XREA(ICOUNT)**2+YIMA(ICOUNT)**2
      HWA2=SQRT(HWA1)
      AMAG(ICOUNT)=20.*ALOG10(HWA2)
C
  481 OLDW=WI
      IF(IREG .EQ. 1.OR.IREG.EQ.2) GO TO 410
      DRAT=CABS(OLDRAT-RATIO)
      IF(IBODE .EQ. 1) GO TO 482
```

321

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      IF(AMRAT.LE.1.E-15) GO TO 410
  482 DRAREL=DRAT/AMRAT
      IF(DRAREL.GT.0.4)GO TO 500
      IF(DRAREL.LE.0.1) GO TO 510
      GO TO 410
  500 W1=W1/WMUL
      WMUL=SQRT(WMUL)
      IF(WMUL .LT. SIGP1) WMUL = 1.0 + SIG/2.0
      GO TO 410
  510 WMUL=WMUL**2
      GO TO 410
 5000 WRITE (6,10) XCHOUT(I)
      STOP
C
 4000 WRITE(6,70) KIP1,KIP2
      STOP
C
 6000 WRITE(6,12)
      STOP
  600 CONTINUE
      IF(ICASE .EQ. 1)WRITE(6,68)VOCAL
   68 FORMAT(///,'VOID COEFFICIENT= ',E12.4)
      WRITE(6,760)
  760 FORMAT(/)
      ICASEO=ICASE
      IF(ICASE .NE. 1)GO TO 423
      WRITE(6,76)
   76 FORMAT(//,17X,'SYSTEM PRESSURE PERTURBATION')
      WRITE(6,760)
      WRITE(6,762)
      WRITE(6,77)(TFW(I),CLMP(I),CLDBP(I),CLAP(I),CLRP(I),
     @   CLIP(I), I=1,IY)
      WRITE(6,78)
   78 FORMAT(//,17X,'CLOSE LOOP , REACTIVITY PERTURBATION')
      WRITE(6,760)
      WRITE(6,761)
      WRITE(6,77)(TFW(I),CLMK(I),CLDBK(I),CLAK(I),CLRK(I),
     @   CLIK(I), I=1,IY)
      WRITE(6,79)
   79 FORMAT(//,17X,'OPEN LOOP , REACTIVITY PERTURBATION')
      WRITE(6,760)
      WRITE(6,761)
      WRITE(6,77)(TFW(I),OPMK(I),OPDBK(I),OPAK(I),OPRK(I),
     @   OPIK(I), I=1,IY)
      WRITE(6,378)
  378 FORMAT(//,17X,'CLOSED LOOP , CORE FLOW PERTURBATION')
      WRITE(6,760)
      WRITE(6,761)
      WRITE(6,77)(TFW(I),CLMW(I),CLDBW(I),CLAW(I),CLRW(I),
     @   CLIW(I), I=1,IY)
      WRITE(6,379)
  379 FORMAT(//,17X,'OPEN LOOP , CORE FLOW PERTURBATION')
      WRITE(6,760)
      WRITE(6,761)
      WRITE(6,77)(TFW(I),OPMJ(I),OPDBJ(I),OPAJ(I),OPRJ(I),
     @   OPIJ(I), I=1,IY)
  423 IF(IBODE .NE. 0)GO TO 520
      ITCT=ICOUNT
      IF(ITCT .LE. 1)GO TO 1089
      ICOUNT = ICOUNT - 1
```

```
C
C   $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
C    *****    SISO STABILITY MARGIN CALCULATION    *****
C
C                *  STM ; MAGNITUDE MARGIN
C                *  STA ; PHASE MARGIN
C
      STM=9999.
      STA=9999.
      KV = 0
      DO 630 I=2,ITCT
      II = I - 1
      KV = KV+1
      YDIF=YIMA(I)*YIMA(II)
      IF(YDIF .GT. 0.) GO TO 630
      XMAG = XREA(II)+(XREA(I)-XREA(II))/(ABS(YIMA(I))+
     @       ABS(YIMA(II)))*ABS(YIMA(II))
      STM = 20.*ALOG10(-1./XMAG)
      GO TO 640
  630 CONTINUE
C
  640 K2 = 0
      XANG = -180.
      IF(1.-AMOD(1) .GT. 0.) GO TO 660
      DO 850 I=2,ICOUNT
      IF(1.-AMOD(I) .LT. 0.) GO TO 850
      II = I-1
      K2 = K2+1
      IF(AMOD(I) .EQ. AMOD(II))GO TO 1090
      XANG=ARGU(II)+(ARGU(I)-ARGU(II))/(AMOD(I)-AMOD(II))*
     1      (1.-AMOD(II))
      GO TO 660
  850 CONTINUE
  660 CONTINUE
      STA = 180.+XANG
      IF(STM .LE. 0 .OR. XANG .GE. 0.) GO TO 1088
      IF(STM .EQ. 9999. .OR. STA .EQ. 9999.) GO TO 1089
      WRITE(6,17) STM, STA
C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C   ******* MIMO STABILITY MARGINS CALCULATION *********
C                   GM = GAIN MARGIN (DB)
C                   PM = PHASE MARGIN (DEGREE)
C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      L=1
      NM=6
      M=4
      N=6
      SVMAXF=100000.
      DO 225 K=1,IY
      DO 230 I=1,4
      DO 235 J=1,6
      IM2=I-2
      JM3=J-3
      IF(I .LE. 2)GO TO 240
      IF(J .LE. 3)GO TO 250
      A(I,J)=REAL(WII(K,IM2,JM3))
      GO TO 235
  250 A(I,J)=AIMAG(WII(K,IM2,J))
      GO TO 235
```

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  240 IF(J .LE. 3)GO TO 245
      A(I,J)=-AIMAG(WH(K,I,JM3))
      GO TO 235
  245 A(I,J)=REAL(WH(K,I,J))
  235 CONTINUE
  230 CONTINUE
      CALL SVD(NM,M,N,A,SV,.FALSE.,U,.FALSE.,V,IERR,WORK)
      IF(IERR .NE. 0)WRITE(6,222)IERR
  222 FORMAT('TROUBLE IERR = ',I4)
      DO 242 I=1,4
  242 SVMAX(K)=AMAX1(SVMAX(K),SV(I))
      SVMAX(K)=1./SVMAX(K)
      SVMAXF=AMIN1(SVMAXF,SVMAX(K))
  225 CONTINUE
      GM=20.*ALOG10(1.+SVMAXF)
      NSIG=SVMAXF/2.
      IF(NSIG .GE. 1)SVMAXF=SVMAXF-2.*FLOAT(NSIG)
      PM=2.*ARSIN(SVMAXF/2.)*180./3.14159
      WRITE(6,255)GM,PM
  255 FORMAT(///,15X,'MIMO STABILITY MARGINS',/15X,
     @          'GAIN  MARGIN = ',F9.4,' (DB)',/15X,
     @          'PHASE MARGIN = ',F9.4,' (DEGREE)')
      WRITE(6,257)
  257 FORMAT(//,24X,'W',10X,'1/SIGMA')
      WRITE(6,256)(TFW(K),SVMAX(K),K=1,IY)
  256 FORMAT(18X,E12.4,2X,E12.4)
  520 CONTINUE
 2089 DO 196 IX=1,2
      IF(IX .EQ. 1)WRITE(6,650)ICASEO
  650 FORMAT(//,17X,'SYSTEM PRESSURE PERTURBATION',5X,
     @          'NEUTRON KINETICS = ',I4)
      IF(IX .EQ. 2)WRITE(6,652)ICASEO,IBODE
  652 FORMAT(//,17X,'POWER DENSITY PERTURBATION',5X,
     @          'NEUTRON KINETICS = ',I4,5X,'IBODE = ',I2)
      IF(IX .EQ. 1)WRITE(6,762)
  762 FORMAT(6X,'W',9X,'MAG(%)',7X,'DB',7X,'ANGL(DGE)',6X,'REAL',
     @          8X,'IMAG')
      IF(IX .EQ. 2)WRITE(6,761)
  761 FORMAT(6X,'W',9X,'MAG',10X,'DB',7X,'ANGL(DGE)',6X,'REAL',
     @          8X,'IMAG')
      WRITE(6,77)(TFW(I),TFM(IX,I),TFDB(IX,I),TFA(IX,I),
     @          TFR(IX,I),TFI(IX,I),I=1,IY)
   77 FORMAT(6E12.4)
  196 CONTINUE
      GO TO 2000
 1088 WRITE(6,20)
      GO TO 2089
 1089 WRITE(6,202)
      GO TO 2089
 1090 CONTINUE
 2000 CONTINUE
      STOP
      END
C
C
C
C
C***********************************
      SUBROUTINE CONSS(I,ICH,ICAL,IWIT)
C***********************************
```

```
C        ....... CALCULATE THE STEADY-STATE CONSTANTS & SYSTEM PARAMETERS
      REAL KF, KLOSS, MUIL ,MARNEL
      COMPLEX DGAMP
      NAMELIST/CALPRO/ ENTHT,ENTHP,DENSF,DENSI,VFG1,RHOG
      NAMELIST/PROPTY/ TSATP,TAVE,HFG1,VISC,CPF,KF,SIGM,DD1,XFRIC
      COMMON/CONST1/ C1(200),C2(200),C3(200),C4,C5(200),C8(200,30),
     1       C9(200,30),C18(200), C21(200), C22(200),C25(200),
     2       C26(200), T6, V7(200), DD1, CKI, CMP
      COMMON/CONST2/ P,VCH,VIN(200),AXS(200),DH(200),DHIN(200),
     1       PH(200),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2       DENSF,VFG1,RHOG,G0(200),G02(200),H0(200),GC,G1,KLOSS(30),
     3       FRICHO(200),VGJH(200,30),COH(200,30),CZERO,VGJ,DPTS,
     4       G02RF(200),HFG1,ZSP(30),NUMBSP(200,30),ALHEAT,CXF(200),
     5       AVEQ,CHOMO1,CHOMO2,XKIN(200),XKEXIT(200)
      COMMON /CUPPER/ RKIN,RKEXIT,AP,RP0,RP1,RP2,CL10(200),
     1   CL11(200),CLT,AXSCH,RAR,AD,DL,DHDL,FDL, F1(200),F2(200),
     2               RJ1(200),RJ2(200),RJ3(200),F3(200)
      COMMCN /CDELHI/ HFW, ADC, PHV, DKV, CPV, DENV, TEMV, TEMINV,
     1               THV, HOD, PLM, AHLP, THLP, HOLP, WO, DLENG
C
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMMON/DELTAP/DGAMP,DRHOG,DHF,DHG,DCZERO,DVGJ,DCOR,DVGJR
      COMMON/SWITCH/IDCZC,IDVGJC,IDCZR,IDVGJR
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
   10 FORMAT(////10X,'***** SYSTEM PROPERTIES *****')
C
      IF(IWIT .GE. 1) GO TO 20
      TSAT=TSATP
      TAVE=(TIN+TSAT)/2.
      ENTHT=HL(P,TIN)
      ENTHP=HF(P)
      HFG1=HFG(P)
      VISC=MUTL(TAVE)/3600.0
      VISDL=MUTL(TSAT)/3600.0
      SIGM = SGMA(P,TSATP)
C
      CPF= (HL(P,TSAT)-ENTHT)/(TSAT-TIN)
      KF=COND(TAVE)/3600.
      DENSI = DENS(P,TIN,DUMB)
      DENSF=DENS(P,TAVE,DUMB)
      VFG1 = VFG(P)
      VGAS =  VFG1 + VF(P)
      RHOG = 1.0/VGAS
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C DETERMONE STATE PARAMETERS AS A FUNCTION OF PRESSURE
      DRHOG=-(RHOG**2)*DVG1(P)
      DHF=DHF1(P)
      DHG=DHG1(P)
      DCZERO=DCZER1(RHOG,DENSF,DRHOG,IDCZC)
      DVGJ=DVGJ1(RHOG,DENSF,DRHOG,TAVE,P,IDVGJC)
      DCOR=DCZER1(RHOG,DENSF,DRHOG,IDCZR)
      DVGJR=DVGJ1(RHOG,DENSF,DRHCG,TAVE,P,IDVGJR)
      IF(IWIT .LT. 2)GO TO 15
      WRITE(6,481) DRHOG,DHF,DHG
      WRITE(6,482) DCZERO,DVGJ,DCOR,DVGJR
  481 FORMAT(' ','DRHOG=',E10.3,'DHF=',E10.3,'DHG=',E10.3)
  482 FORMAT(' ','DCZERO=',E10.3,'DVGJ=',E10.3,'DCOR=',E10.3,'DVGJR=
     @ ',E10.3)
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
   15 CONTINUE
```

```
      DH(I) = DHIN(I)/12.0
C
C  20 VIN(I) = VCH*DENSI/DENSF
   20 VIN(I)=VCH
      GO(I)=DENSF*VIN(I)
      GO2(I) = GO(I)**2
      GO2RF(I) = GO2(I)/(2.0*DENSF*GC)
      HO(I)=KF/DH(I) * .023 * (DENSF*VIN(I)*DH(I)/VISC)**(0.8)
     1         * (CPF*VISC/KF)**(0.4)
C
C     * CALCULATION OF THE SINGLE-PHASE DARCY-WEISBACH FRICTION FACTOR
C              BY FITTING THE MOODY CURVES
C        @  RPD ; SURFACE ROUGHNESS / DH(I)  IN COMMERCIAL STEEL PIPE
C        @  RE  ; RENOLD'S NUMBER
      RPD = -1.41E-05*DHIN(I) + 3.36E-04
      RE  =  GO(I)*DH(I)/VISC
      FRICMO(I) = 0.0055*(1.0 + (20000.*RPD + 1.0E+06/RE)**(1./3.) )
C
      IF(ICAL .GE. 2 ) GO TO 200
       GO TO 201
  200 RDL = -1.41E-05*(DHDL/12.0) + 3.36E-04
      REDL = (WO/AD)*DHDL/VISDL
      FDL = 0.0055*(1.0+(20000.*RDL + 1.0E+06/REDL)**(1./3.) )
      FDL=.184/(2.*DHDL*REDL**.2)
C
  201 IF(IWIT .GE. 1) GO TO 30
      T6 = GI/GC*DENSF
      C4 = DENSF - RHOG
      C5(I) = PH(I)*VFGI/(AXS(I)*HFGI)
      C25(I) = C4*PH(I)/AXS(I)/DENSF
C     C26(I) = 1.14677E-06 * (3.*CCON(P)/CPF)
C
   30 V7(I) = FRICMO(I)*GO(I)*VIN(I)/(2.*GC*DH(I))
      C1(I) = PH(I)/(DENSF*VIN(I)*CPF*AXS(I))
      C2(I) = V7(I) + T6
      C3(I) = FRICMO(I)*GO(I)/(GC*DH(I))
      C18(I) = CXF(I)/(GO(I)*AXS(I))
      DD1 = MARNEL(P,GO(I)) * (1.2*(DENSF/RHOG) - 1.)
      XFRIC=MARNEL(P,GO(I))
C
      IF(IWIT .GE. 1) GO TO 100
      IF(ICH .EQ. 0) GO TO 100
      WRITE(6,10)
      WRITE(6,CALPRO)
      WRITE(6,PROPTY)
  100 RETURN
      END
C
C
C
C
C*******************************************************
      SUBROUTINE STEADY(NODES,INODE,ICH,ICAL,IWIT,CHALF,RPWR)
C*******************************************************
C     * CALCULATE STEADY-STATE VALUES
C     * LAMBDA ; BOILING BOUNDARY
C     * JOIN(I) ; NODE INLET FLOW VELOCITY
C     * DOIN(I); NODE INLET DENSITY
C     * XEXIT ; STEADY-STATE CHANNEL EXIT QUALITY
C     * ALFNOD(INODE,I) ; NODE AVERAGE VOID FRACTION
```

```
C
      REAL K1,JOIN,KF,KLOSS
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMPLEX CLTX,RR4
      COMPLEX CSBX3, DGAMP,VPL
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      DIMENSION DPH2PG(30), H(30),CZ(30),VGZ(30),TWALL(30),DPSP(30),
     1      DPH2PF(30),DPH2PA(30),DPH2P(30),TLIQ(30),CKSP(30),
     2      XEXIT(30), JOIN(30),RPWR(5)
      DOUBLE PRECISION XAVG,OMG,DELOMG,CTEM0,CTEM1,CTEM2,CTEM3,OMIN,
     1       OMAX, SBHOUT(30),SBHIN(30),V1(30),ALPOUT(30),AVGH(30),
     2       VOOUT(30),CKOUT(30),OLDOMG(100),DIFF(100),C15(30),
     3       C101(30),C103(30),C104(30),C105(30),C16(30),
     4       C107(30),C108(30),C109(30),C110(30)
C
      NAMELIST/PLCT/PE,ENTHP,QFLUX,GFLUX,CRIT,DH,CPF,KF
      COMMON/OPTION/ IOSUB, IOHW, IO2Q, IPILO, ISLIP, IRW
      COMMON/CONST1/ C1(200),C2(200),C3(200),C4,C5(200),C8(200,30),
     1       C9(200,30),C18(200), C21(200), C22(200),C25(200),
     2       C26(200), T6, V7(200), DD1, CKI, CMP
      COMMON/CONST2/ P,VCH,VIN(200),AXS(200),DH(200),DHIN(200),
     1       PH(200),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2       DENSF,VFG1,RHOG,G0(200),G02(200),H0(200),GC,G1,KLOSS(30),
     3       FRICMO(200),VGJH(200,30),COH(200,30),CZERO,VGJ,DPTS,
     4       G02RF(200),HFG1,ZSP(30),NUMBSP(200,30),ALHEAT,CXF(200),
     5       AVEQ,CHOMO1,CHOMO2,XKIN(200),XKEXIT(200)
      COMMON /CONWD1/ CPH,TKH,DENSH,CPC,TKC,DENSC,CRS,CRI,CRO,
     1               GAPC,V22(200,30), THICKH
C
      COMMON /RISER/ COR,VGJR,CKRO,RL,AR,DRIN,DR,PI,CL1,CL2,CL3,CL4,
     1    CL5, CL6, CR5, CR6, UPJ1(200), UPJ2(200), RO11, RO12,
     2               RO21, RO22, XROUT, UPJIN
      COMMON /CLOOP/ SLOOP, SFLOOP, RLOOP,AA,
     @               VL1(200), VL2(200), VL3(200), DPLPT,RATW
      COMMON/CUPPER/RKIN,RKEXIT,AP,RP0,RP1,RP2,CL10(200),CL11(200),
     1              CLT,AXSCH,RAR,AD,DL,DHDL,FDL, F1(200),F2(200),
     2              RJ1(200),RJ2(200),RJ3(200),F3(200)
      COMMON /CDELH1/ HFW, ADC, PHV, DKV, CPV, DENV, TEMV, TEMINV,
     1               THV, HOD, PLM, AHLP, THLP, HOLP, WO, DLENG
      COMMON /CDELH2/ CH1, CH2, CH3, CH4, CH5, CH7, CH8, CH9, CH10
C
      COMMON/CONSS1/ QDIS(200,30),Q0(200,30),DZ(200,30),Z(200,30),
     1       K1(200,30), CKIN(200,30), ZETA(200,30), DOIN(200,30),
     2       DOOUT(200,30),ALPIN(200,30),BEE(200,30),CP11(200,30),
     3       COR2PH(200,30), ZETSP(200,30), WIN
      COMMON /DIM1/ DELX, DELZ, CHLAMB(200), ALFNOD(200,30),
     1              BBLAMB(200)
      COMMON/CONSS2/ NTO1(200),NBB(200),NBB1(200),NSP,N1PSP(200),
     1              K2PSP(200), NDP(200), NDP1(200), ISUB(200)
      COMMON/PCHOUT/XCHOUT(200), ACHOUT(200), CCHOUT(200)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMMON/RISERP/CL1X,RR4,CRP5,CRP8,RO13,RO23,CL12,UPJ3,ALPRO
     1              ,GOR,RHOR,VRO,CRCON,UPALP
      COMMON/SWITCH/IDCZC,IDVGJC,IDCZR,IDVGJR
      COMMON/PXX/PXEXT(200,30)
      COMMON/PSP/CSBX3(200,30),ALOUT(200,30)
      COMMON/YYY/ZLUP,FLUP,GOU,DHUP,ROUP,FUP,ZLR,FLR,ROR,FRR
     @         ,ADLP,DHLP,ZLLP,FLLP,XKLP,GOLP,FLP
     @         ,AD1,DH1,ZL1,FL1,XK1,GO1,FD1
     @         ,AD2,DH2,ZL2,FL2,XK2,GOD2,FD2
     @          ,AD3,DH3,ZL3,FL3,XK3,GO3,FD3
     @          ,SPUMP,CPUMP
      COMMON/DELTAP/DGAMP,DRHOG,DHF,DHG,DCZERO,DVGJ,DCOR,DVGJR
      COMMON/PIV/IV
      COMMON/VV4/PL1,PL2,PL4
      COMMON/VV5/VPL
      COMMON/PGAM/IGAM,IDRF
      COMMON/PCO/ICO
C   QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
C    * VIN IS THE AVERAGE VELOCITY IN THE SINGLE-PHASE REGION.
C            ALL CALCULATIONS ARE BASED ON THIS VELOCITY.
C
C    ......................................................................
C    * FORMAT STATEMENTS
C    ......................................................................
    3 FORMAT(/10X, '***   NO BULK BOILING ALONG THE CHANNEL ; HEXIT =',
     1             E12.4, '  (BTU/LBM)   ***')
    5 FORMAT(/3X,'STEADY STATE VOID FRACTION WITH CONSTANT CO &VGJ')
    7 FORMAT(/3X,'STEADY STATE VOID FRACTION WITH VARIABLE CO &VGJ')
    9 FORMAT(2E15.5)
   11 FORMAT(//,'CHANNEL GEOMETRY & BOILING BOUNDARY',//'TYPE',2X,
     1       'FLOW AREA', 2X,'HEAT PERI.', 2X,'HYDR.DIAM.', 2X,
     2       'BOIL.BOUND.', 2X, 'FUEL AREA ',2X,'   VIN    ',2X,
     3       '    KIN    ',2X,'   KEXIT ',2X,'POWER DIS.',
     4       /,I3,2X,8(E10.4,2X),E10.4)
   41 FORMAT(///'HEATED WALL DYNAMICS PARAMETER')
   43 FORMAT(/5X, '*****  NO HEATER WALL DYNAMICS  ****' )
   45 FORMAT(/5X,'*** LAMPED PARAMETER MODEL ***',
     1    //10X,'SPECIFIC HEAT OF HEATER    =', E12.6, '(BTU/LB-F)'
     2     /10X,'DENSITY OF HEATER          =', E12.6, '(LB/FT3)')
   47 FORMAT(/5X,'***   TWO-PARALLEL PLATE HEATER   ***',//10X,
     1       'SPECIFIC HEAT OF HEATER    =',E12.6,'(BTU/LB-F)',/10X,
     2       'DENSITY OF HEATER          =',F9.4, '(LB/FT3)'  ,/10X,
     3       'THICKNESS OF HEATER        =',F9.4, '(FT)'      )
   49 FORMAT(/5X,'***   CYLINDRICAL INTERNALLY HEATING TUBE   ***',
     1 /10X, 'SPECIFIC HEAT OF HEATER    =',E12.6,'(BTU/LB-F)',/10X,
     2       'DENSITY OF HEATER          =',F9.4, '(LB/FT3)'  ,/10X,
     3       'INNER RADIUS OF TUBE       =',F9.4, '(FT)'      ,/10X,
     4       'OUTER RADIUS OF TUBE       =',F9.4, '(FT)'      )
   51 FORMAT(/5X,'***   HOMOGENIZED FUEL ASSEMBLY   ***',//7X,
     *       '* FUEL REGION'/10X,
     1       'SPECIFIC HEAT OF FUEL    =',E12.6,'(BTU/LB-F)',/10X,
     2       'THERMAL CONDUCTIVITY     =',E12.6,'(BTU/S-FT-F)',/10X,
     3       'DENSITY OF FUEL          =',F9.4, '(LB/FT3)'  ,/10X,
     4       'FUEL RADIUS              =',F9.4, '(IN)'      ,//7X,
     5       '* CLAD REGION'/10X,
     6       'SPECIFIC HEAT OF CLAD    =',E12.6,'(BTU/LB-F)',/10X,
     7       'THERMAL CONDUCTIVITY     =',E12.6,'(BTU/S-FT-F)',/10X,
     8       'DENSITY OF CLAD          =',F9.4, '(LB/FT3)'  ,/10X,
     9       'INNER RADIUS OF CLAD     =',F9.4, '(IN)'      ,/10X,
     *       'OUTER RADIUS OF CLAD     =',F9.4, '(IN)'      ,//7X,
     1       'GAP CONDUCTANCE          =',E12.6,  '(BTU/FT2-F)')
   57 FORMAT(//10X,'NODE',11X,'Z',7X,'HEAT FLUX',7X,'POWER DENSITY')
   59 FORMAT(/10X, '***** TWO-PHASE REGION *****')
   61 FORMAT(/10X,I3,5X,F10.4,3X,F10.4,8X,E12.6,2(7X,F6.2))
   67 FORMAT(1X,///,'NODE VOID PROPERTIES',//5X,'NODE',5X,'DELZ',
     1    8X,'KI',13X,'CO(Z)', 5X,'VGJ(Z)', 6X,'AVG.VOID',4X,'XEXIT(Z)',
     2    6X,'AVG.ENTH.',8X,'JOIN')
   69 FORMAT(/5X,I4,2X,F9.4,3X,E10.4,3(3X,F9.4),2(3X,E12.5),3X,E12.4)
   71 FORMAT(///'LOCAL PRESSURE DROP BY SPACER',
     1       //11X,'Z', 13X,'LOCAL COEFF.', 7X,'LOCAL DP')
   73 FORMAT(/6X,F9.4,  10X,E12.6,  5X,E12.6)
   75 FORMAT(1X,///,'STEADY-STATE PRESSURE DROP',//3X,
     1    '     SINGLE-PHASE REGION',/6X,'LOCAL LOSS =',F10.4,'(PSI)',
     2    /6X,'GRAVITY =',F10.4,'(PSI)',16X,'FRICTION =',F10.4,
     3     '(PSI)',/6X,'TOTAL DP =',F10.4,'(PSI)')
   77 FORMAT(///3X,'    TWO-PHASE REGION',  //27X,'GRAVITY', 9X,
     1     'FRICTION(COR2PH)', 9X,'ACCELERATION', 5X,'TOTAL',
     2    /6X, 'NODE', 5X,'Z', 12X,'(PSI)', 10X,'(PSI)',
     3     6X,7X, 10X,'(PSI)',10X,'(PSI)'  )
   79 FORMAT(/5X,I4, F10.4, 2(5X,F10.4), ' (',F9.4,')', 2(5X,F10.4))
   81 FORMAT(/6X,'TOTAL',13X,F10.4,5X,F10.4,17X,F10.4,5X,F10.4,
     @       //6X,'LOCAL LOSS =',F10.4,'(PSI)',
     @      /3X,'TOTAL CHANNEL PRESSURE DROP =',F10.4,'(PSI)')
C
   85 FORMAT(/10X,'***   THE ITERATION FOR S.B. IS DIVERSE  ***')
   87 FORMAT(/10X, '***   ERROR ; EXIT QUALITY (', F9.4,
     1             ' )  IS GREATER THAN 1.  ***' )
C     ...........     COMMENTS      .................................
C     ISUB = 0    ;   THERE IS SINGLE-PHASE REGION
C          = 1    ;   NO SINGLE-PHASE REGION
C     IWIT = 0    ;   SINGLE CH. CALC. OR INITIAL CALC. FOR MULTI-CH.
C                       CALCULATION
C          = 1    ;   MULTI-CHANNEL CALCULATION
C          = 2    ;   FINAL CALCULATION FOR MULTI-CHANNEL CALCULATION
C     NDP1  ;  FIRST NODE INDEX IN THE SUBCOOLED BOILING REGION
C     NBB1  ;  FIRST NODE INDEX IN THE BULK BOILING REGION
C     .................................................................
      DRF=DRFDP(P)
      IF(IDRF .EQ. 0)DRF=0.
      DDR=DRHOG-DRF
      DRGFP=DRHOG-RHOG/DENSF*DRF
      IF(IWIT .GE. 1) GO TO 100
      H(1) = ENTHT
      CRIT = ENTHP
C     IF(ISLIP .EQ. 1) GO TO 101
       AA1 = 23.
       AA2 = 0.
C     GO TO 100
C 101  AA1 = 4.
C      AA2 = 2.
  100 GOHR = GO(INODE)*3600.0
      DHI=DH(INODE)
      PE = GO(INODE)*DH(INODE)*CPF/KF
C
C    * DETERMINE THE VOID DEPARTURE POINT WITH SAHA & ZUBER'S MODEL
C
        ISUB(INODE) = 0
        ITER = 0
        IBB = 0
        NP1 = NODES
        INNSP=0
      DO 120 J=1,NP1
        JNOD = J
        JA = J + 1
        JN = J - 1
        QFLUX = QDIS(INODE,J)*CXF(INODE)/PH(INODE)
        BEF(INODE,J) = QDIS(INODE,J) /AVEQ
        QO(INODE,J) = QFLUX
```

```
          H(JA) = H(J) + QFLUX*PH(INODE)*DZ(INODE,J)/AXS(INODE)/
     1                   GO(INODE)
          IF(IOSUB .EQ. 0) GO TO 1000
          IF(PE .LE. 7.0E+04) GO TO 122
           GFLUX=GO(INODE)
           SBX1=-154./GO(INODE)
           SBX2=154.*QFLUX/GO(INODE)**2
           CRIT = ENTHP - 1.53846E+02*QFLUX/GO(INODE)
C          WRITE(10,PECT)
          IF(H(JA) .GE. CRIT) GO TO 123
          GO TO 120
  122      CRIT = ENTHP - 2.1978E-03*QFLUX*DH(INODE)*CPF/KF
          GFLUX=GO(INODE)
          SBX1=-.0022*DH(INODE)*CPF/KF
          SBX2=0.
C         WRITE(10,PECT)
          IF(H(JA) .GE. CRIT) GO TO 123
          GO TO 120
 1000     IF(H(JA) .GE. ENTHP) GO TO 124
  120 CONTINUE
C
  123     IF(H(1) .GE. CRIT) GO TO 150
C
  124      NDP(INODE) = JNOD
           INN = NDP(INODE)
           NDP1(INODE) = JNOD + 1
           NDM2 = JNOD - 1
           IF(NDM2 .EQ. 0)NDM2=1
          IF(IOSUB .EQ. 0) GO TO 1001
           DZVD = (CRIT-H(JNOD))*AXS(INODE)*GO(INODE)/QFLUX/PH(INODE)
          IF(DZVD .LT. 0.) GO TO 131
          GO TO 140
 1001      DZVD = (ENTHP-H(INN))*GO(INODE)*AXS(INODE)/(QDIS(INODE,INN)
     1           *CXF(INODE))
          GO TO 140
  131      QFLUX=(QO(INODE,JNOD)+QO(INODE,NDM2))/2.
           CRIT = ENTHP - 1.53846E+02*QFLUX/GO(INODE)
           IF(PE .LE. 7.0E+04) CRIT = ENTHP - 2.1978E-03*QFLUX*DH(INODE)
     1           *CPF/KF
           DZVD = (CRIT-H(NDM2))*AXS(INODE)*GO(INODE)/QFLUX/PH(INODE)
          IF(DZVD .GE. DZ(INODE,NDM2)) GO TO 132
           NDP(INODE) = NDM2
           NDM2 = NDM2 - 1
           INN = NDP(INODE)
           NDP1(INODE) = INN + 1
          GO TO 140
  132      DZVD = DZVD - DZ(INODE,NDM2)
  140     IF(NDM2 .EQ. 0) GO TO 141
           ZSUM = 0.
        DO 142 I=1,NDM2
           ZSUM = ZSUM + DZ(INODE,I)
           Z(INODE,I) = ZSUM
  142     CONTINUE
            CHLAMB(INODE) = ZSUM + DZVD
        GO TO 143
  141       CHLAMB(INODE) = DZVD
C
C    * NODE REDISTRIBUTION IN THE SUBCOOLED BOILING REGION
C
  143 IF(CHLAMB(INODE) .LE. 0.)CHLAMB(INODE)=0.005
```

```
      CALL ASSIGN(NDP(INODE), NP1, CHLAMB(INODE), 0, INODE, 0)
      GO TO 160
C
  150   ISUB(INODE) = 1
        NDP1(INODE) = 1
      GO TO 170
  160   NP1 = NP1 + 1
  170   INN1 = NDP1(INODE)
C     . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C    * CALCULATE THE THERMAL PARAMETERS IN THE SUBCOOLED BOILING
C                       REGION
C     . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C
C       C101(J) = ALPIN(INODE,J)
C       C103(J) = JOIN(J)
C       C104(J)= CKIN(INODE,J)
C       C105(J) = ZETA(INODE,J)
C       C106(J) = DOOUT(INODE,J)
C       C107(J) = XEXIT(J)
C       C108(J) = ALFNOD(INODE,J)
C       C109(J) = CSB2(INODE,J)
C       C110(J) = CSB3(INODE,J)
C
  190 DO 200 I=1,INN1
        C103(I) = VIN(INODE)
        C104(I) = C103(I)
        C101(I) = 0.
        DOIN(INODE,I) = DENSF
  200 CONTINUE
      IST = 0
      DO 201 I=INN1,NP1
       COH(INODE,I) = CZERO
       VGJH(INODE,I) = VGJ
  201 CONTINUE
      GO TO 202
 9000 DO 203 I=INN1,NP1
       COH(INODE,I) = CZ(I)
       VGJH(INODE,I) = VGZ(I)
  203 CONTINUE
  202 C104(INN1) = COH(INODE,INN1)*C103(INN1)+VGJH(INODE,INN1)
      DO 204 I=INN1,NP1
        C15(I) = DENSF/(C4*COH(INODE,I))
        C16(I) = COH(INODE,I)*RHOG/DENSF + RHOG*VGJH(INODE,I)/GO(INODE)
  204 CONTINUE
       IF(IOSUB .EQ. 0) GO TO 1002
        SBHIN(INN1) = CRIT
       IF(ISUB(INODE) .GT. 0) SBHIN(INN1) = H(1)
C
      OMG[illegible] 01
      DO [illegible] J=INN1, NP1
       J[illegible] J + 1
       JN = J - 1
       IBUN = 1
        QFLUX = QDIS(INODE,J)*CXF(INODE)/PH(INODE)
C       OLDOMG(1) = PH(INODE)*QFLUX*VFG1/AXS(INODE)/HFG1
       IF(J .GT. INN1)OMGGS=K1(INODE,JN)
       OLDOMG(1)=OMGGS
       OMAX = OLDOMG(1)
       OMIN = 0.
       IF(J .EQ. INN1) GO TO 211
      C101(J) = ALPOUT(JN)
      SBHIN(J) = SBHOUT(JN)
      DOIN(INODE,J) = DENSF - C4*C101(J)
      C103(J) = VOOUT(JN)
      C104(J) = COH(INODE,J)*C103(J) + VGJH(INODE,J)
C
  211 IF(IBUN .GT. 200) GO TO 2000
C     CRIT=ENTHP+SDX1*QFLUX
      VOOUT(J) = C103(J) + DZ(INODE,J)*OLDOMG(IBUN)
      AVGJ = (C103(J)+VOOUT(J))/2.
C     A1 = 1./(1.+AA1*(AVGJ/VIN(INODE))**AA2)
      A1=.041667
      CKOUT(J) = COH(INODE,J)*VOOUT(J) + VGJH(INODE,J)
      C105(J) = CKOUT(J)/C104(J)
      ALPOUT(J) = C15(J)*(1.-(1./C105(J))) + C101(J)
     1                               *(1./C105(J))
      ALOUT(INODE,J)=ALPOUT(J)
      DOOUT(INODE,J)= DENSF - C4*ALPOUT(J)
      C107(J)  = ALPOUT(J)*C16(J)/(1.-ALPOUT(J)/C15(J))
      V1(J) = C104(J)/(COH(INODE,J)*OLDOMG(IBUN)*DZ(INODE,J))
      C108(J) = V1(J) * (C15(J)*(C105(J)-1.) +
     1       (C101(J) - C15(J))*DLOG(C105(J)))
      XAVG = C108(J)*C16(J)/(1.-C108(J)/C15(J))
      CTEMO = GO(INODE)*VFG1*(1.-XAVG)*COH(INODE,J)
      C109(J) = C104(J)/CTEMO
      C110(J) = (QFLUX*PH(INODE)*VFG1/AXS(INODE)-OLDOMG(IBUN)
     1         *(ENTHP+HFG1)) / (CTEMO*OLDOMG(IBUN)/C104(J))
      CTEM1 = -C110(J)/C109(J)
      CTEM2 = (SBHIN(J)-CTEM1) * DEXP(-C109(J))
      CTEM3 = C109(J)*C105(J)
      SBHOUT(J) = CTEM2*DEXP(CTEM3) + CTEM1
      AVGH(J) = (SBHOUT(J)+SBHIN(J))/2.
C
      OMG = C25(INODE)*QFLUX*(AVGH(J)-CRIT)/(ENTHP-CRIT)/(RHOG*
     1       HFG1+DENSF*(ENTHP-AVGH(J))) - A1*C108(J)*
     2       (ENTHP-AVGH(J))
C
      DIFF(IBUN) = (OLDOMG(IBUN) - OMG)
C     DELOMG = DIFF(IBUN) / OMG
      DELOMG=DIFF(IBUN)/OLDOMG(IBUN)
C
      IF(DABS(DELOMG) .LE. 5.0E-03) GO TO 212
      IBUN2 = IBUN - 1
      IBUN1 = IBUN
      IBUN = IBUN + 1
      OLDOMG(IBUN)=OMG
      GO TO 211
C
  212 IF(C105(J)-1. .LE. 1.0E-05) GO TO 224
      K1(INODE,J) = OMG
      QO(INODE,J) = QDIS(INODE,J)*CXF(INODE)/PH(INODE)
      BFE(INODE,J) = QDIS(INODE,J) / AVEQ
      ALPIN(INODE,J) = C101(J)
      JOIN(J) = C103(J)
      CKIN(INODE,J) = C104(J)
      ZETA(INODE,J) = C105(J)
      XEXIT(J) = C107(J)
      PXEXI(INODE,J)=XEXIT(J)
      ALFNOD(INODE,J) = C108(J)
      GO TO 228
  224 MP1=NP1-1
      Z(INODE,INN) = Z(INODE,INN1)
      DZ(INODE,INN) = DZ(INODE,INN) + DZ(INODE,INN1)
      DO 225 I=INN1,MP1
      II = I + 1
      Z(INODE,I) = Z(INODE,II)
      DZ(INODE,I) = DZ(INODE,II)
      QDIS(INODE,I) = QDIS(INODE,II)
  225 CONTINUE
      GO TO 190
C
C    * PARAMETERS FOR THE SUBCOOLED BOILING REGION CALCULATION
C
  228 CONTINUE
      CTEM4 = CTEMO*K1(INODE,J)/CKIN(INODE,J)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C     YSTAR(INODE,J)=(AVGH(J)-CRIT)/(RHOG*HFG1
C    1             +DENSF*(ENTHP-AVGH(J)))**2
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      IF(IST .NE. 1) GO TO 234
      IF(J .EQ. NBB(INODE)) GO TO 301
  234 IF(ITER .EQ. 1) GO TO 300
       IF(J .EQ. 1) GO TO 230
        Z(INODE,J) = Z(INODE,JN) + DZ(INODE,J)
       GO TO 231
  230   Z(INODE,J) = DZ(INODE,J)
  231   DIFFH = SBHOUT(J) - ENTHP
       IF(ABS(DIFFH) .LE. 0.1) GO TO 250
        IF(SBHOUT(J) .GE. ENTHP) GO TO 240
       GO TO 299
C
C    * DETERMINE THE BULK BOILING POINT & NODE REDISTRIBUTION IN THE
C                  TWO-PHASE REGION
C
  240 IF(IST .EQ. 1) GO TO 301
      DZBB = DZ(INODE,J)*(ENTHP-SBHIN(J))/(SBHOUT(J)-SBHIN(J))
       IF(J .EQ. 1) GO TO 241
        BBLAMB(INODE) = Z(INODE,JN) + DZBB
       GO TO 242
  241   BBLAMB(INODE) = DZBB
  242   NBB(INODE) = J
        NBB1(INODE) = J + 1
        ISU = 1
       IF(H(1) .GT. CRIT) ISU = 0
       IF(BBLAMB(INODE) .LE. 0.)BBLAMB(INODE)=0.005
      CALL ASSIGN(NBB(INODE), NP1, BBLAMB(INODE), ISU, INODE, 1)
        IBUN = 1
        OLDOMG(IBUN) = OLDOMG(1)
        ITER = 1
       GO TO 211
C
  250  BBLAMB(INODE) = Z(INODE,J)
       NBB(INODE) = J
       NBB1(INODE) = J + 1
       IMM1 = NBB1(INODE)
       IF(IMM1 .GT. NP1) GO TO 310
       GO TO 301
  299 CONTINUE
       NBB(INODE) = NP1
       NBB1(INODE) = NP1 + 1
      WRITE(6,3) SBHOUT(NP1)
      GO TO 310
C
C    * CALCULATE CHARACTERISTIC PARAMETERS IN THE TWO-PHASE REGION
C
  300   NP1 = NP1 + 1
        IMM1 = NBB1(INODE)
       GO TO 301
 1002   IMM1 = NDP1(INODE)
         DBLAMB(INODE) = CHLAMD(INODE)
  301 IF(NBB(INODE) .EQ. NP1) GO TO 311
      DO 302 I=IMM1,NP1
       INM1 = I - 1
      Z(INODE,I) = Z(INODE,INM1) + DZ(INODE,I)
  302 CONTINUE
      DO 303 I=IMM1,NP1
        IN = I - 1
        AVGH(I) = ENTHP
C       PVGH(INODE,I)=AVGH(I)
        C15(I) = DENSF/(C4*COH(INODE,I))
        C16(I) = COH(INODE,I)*RHOG/DENSF+RHOG*VGJH(INODE,I)/GO(INODE)
        QO(INODE,I) = QDIS(INODE,I)*CXF(INODE)/PH(INODE)
        BEE(INODE,I) = QDIS(INODE,I) / AVEQ
        K1(INODE,I) = PH(INODE)*QO(INODE,I)*VFG1/(AXS(INODE)*HFG1)
        IF(IOSUB .EQ. 0 .AND. I .EQ. IMM1) GO TO 304
        JOIN(I) = VOOUT(IN)
        CKIN(INODE,I) = COH(INODE,I)*JOIN(I) + VGJH(INODE,I)
        ALPIN(INODE,I) = ALPOUT(IN)
        DOIN(INODE,I) = DENSF - C4*ALPIN(INODE,I)
         GO TO 305
  304   JOIN(I) = VIN(INODE)
        CKIN(INODE,I) = COH(INODE,I)*JOIN(I) + VGJH(INODE,I)
        ALPIN(INODE,I) = 0.
  305   VOOUT(I) = JOIN(I) + DZ(INODE,I)*K1(INODE,I)
        CKOUT(I) = COH(INODE,I)*VOOUT(I) + VGJH(INODE,I)
        ZETA(INODE,I) = CKOUT(I) / CKIN(INODE,I)
        ALPOUT(I) = C15(I)*(1.-1./ZETA(INODE,I)) + ALPIN(INODE,I)/
     1                     ZETA(INODE,I)
        ALOUT(INODE,I)=ALPOUT(I)
        DOOUT(INODE,I)= DENSF - C4*ALPOUT(I)
        V1(I) = CKIN(INODE,I) / (COH(INODE,I)*K1(INODE,I)*DZ(INODE,I))
        ALFNOD(INODE,I) = V1(I) * (C15(I)*(ZETA(INODE,I)-1.) +
     1           (ALPIN(INODE,I) - C15(I))*ALOG(ZETA(INODE,I)))
        XEXIT(I)=ALPOUT(I)*C16(I)/(1.-COH(INODE,I)*C4*ALPOUT(I)/DENSF)
        PXEXI(INODE,I)=XEXIT(I)
  303 CONTINUE
  310 CONTINUE
  311 IF(ICAL .GT. 0 .AND. ICAL .LT. 4) GO TO 390
      IF(IRW .EQ. 0) GO TO 312
      IF(IWIT .LE. 1) GO TO 390
  312 IFILE = IST + 1
      IF(IST .EQ. 0) WRITE(IFILE,5)
      IF(IST .EQ. 1) WRITE(IFILE,7)
      DO 320 I=INN1,NP1
C      ZAXIS = (Z(INODE,I)-DZ(INODE,I)/2.)*30.48
       ZAXIS = Z(INODE,I)-DZ(INODE,I)/2.
       XEQM = (ENTHT-ENTHP+QFLUX*PH(INODE)*ZAXIS/AXS(INODE)
     1           /GO(INODE)) / HFG1
C      WRITE(IFILE,9) ZAXIS, ALFNOD(INODE,I)
       WRITE(IFILE,9) XEQM, ALFNOD(INODE,I)
  320 CONTINUE
  390 IF(ISLIP .EQ. 0) GO TO 500
      IF(IST .EQ. 1) GO TO 500
C
C    * Determine CO & Vgj for each node with Okawa & Lahey model
C
      PC0 = RHOG / DENSF
      PC1 = SQRT(PC0)
      XC1 = 0.588116 - 1.81701*PC1 + 2.00025*PC1**2 - 3.34398*PC1**3
      YC0 = 4.72085 - 17.26736*PC1 + 56.14883*PC1**2 + 113.216*PC1**3
     1      - 1250.603*PC1**4 + 3039.767*PC1**5 - 2431.823*PC1**6
      YC1 = AMAX1(YC0,3.136)
      VGJ0 = (32.2*G1*SIGM*C4)**0.25 / SQRT(DENSF)
      VGJ1 = 2.9*VGJ0
      DO 400 I=INN1,NP1
      VGJ2 = YC1*VGJ0*(1.-((ALFNOD(INODE,I)-XC1)/(1.-XC1))**2)
      C00 = -18.*ALFNOD(INODE,I)
      C01 = (1.2-0.2*PC1) * (1.-EXP(C00))
      C02 = 1.+0.2*(1.-PC1)*(1.-((ALFNOD(INODE,I)-XC1)/(1.-XC1))**2)
      IF(ALFNOD(INODE,I) .GE. XC1) GO TO 401
       VGZ(I) = VGJ1
       CZ(I) = C01
      GO TO 400
  401  VGZ(I) = AMIN1(VGJ1,VGJ2)
       CZ(I) = AMIN1(C01,C02)
  400 CONTINUE
      ITER = 0
      IST = 1
      GO TO 9000
C
  500 NTOT(INODE) = NP1
      IF(IOSUB .EQ. 0)GO TO 626
      NBM1=NBB(INODE)
      XTEMO=GO(INODE)*VFG1*(1.-XEXIT(NBM1))*COH(INODE,NBM1)
      BSB2=CKOUT(NBM1)/XTEMO
      B110=(QO(INODE,NBM1)*PH(INODE)*VFG1/AXS(INODE)-
     @       K1(INODE,NBM1)*(ENTHP+HFG1))/(XTEMO*K1(INODE,NBM1)/
     @       CKOUT(NBM1))
      BTEM1=-B110/BSB2
      BTEM2=(SBHIN(NBM1)-BTEM1)*EXP(-BSB2)
      THETAB=-K1(INODE,NBM1)*COH(INODE,NBM1)/(CKIN(INODE,NBM1)*
     @           BSB2*BTEM2)*EXP(-BSB2)
  626 CONTINUE
C
C    * CHANNEL EXIT PARAMETERS
C
      XCHOUT(INODE) = XEXIT(NP1)
      CCHOUT(INODE) = CKOUT(NP1)
      ACHOUT(INODE) = ALPOUT(NP1)
      DO 501 I=INN1,NP1
        AVQT = C16(I)*ALFNOD(INODE,I)/(1.-ALFNOD(INODE,I)/C15(I))
       IF(IPILO .LT. 1) GO TO 502
        CP11(INODE,I) = DD1*AVQT**(-0.176)/(VFG1*DENSF)
        CP12 = 1.
       GO TO 503
  502   CP11(INODE,I) = CHOMO1
        CP12 = CHOMO2
  503   C8(INODE,I) = (CP12-CP11(INODE,I)) - CP11(INODE,I)*DENSF*
     1          VGJH(INODE,I)/(COH(INODE,I)*GO(INODE))
        C9(INODE,I) = (CP11(INODE,I)*DENSF) * (1.+DENSF*VGJH(INODE,I)/
     1        (COH(INODE,I)*GO(INODE))) / (DENSF - COH(INODE,I)*C4*
     2        ALPIN(INODE,I))
        COR2PH(INODE,I) = C8(INODE,I) + C9(INODE,I)*(ZETA(INODE,I)+1)
     1                  /2.
  501 CONTINUE
       IF(IRW .EQ. 0) GO TO 505
       IF(IWIT .LE. I) GO TO 604
  505 C21(INODE) = K1(INODE,INN1)/(RHOG*VFG1*CKIN(INODE,INN1))
       IF(ISUB(INODE) .GT. 0) C21(INODE) = 0.
      C6 = (GO(INODE)*VIN(INODE)/CKIN(INODE,INN1)) * (1./GC)
      C7 = DENSF*RHOG*(VGJH(INODE,INN1)+(COH(INODE,INN1)-1.)*VIN(INODE)
     1     )**2 / (C4*CKIN(INODE,INN1)) * (1./GC)
      C22(INODE) = (C6+C7)*K1(INODE,INN1) + C2(INODE)
C
C     * CALCULATE WALL & BULK TEMPERATURE WITH ASSUMING THAT THE BULK
C              TEMPERATURE IN THE TWO-PAHSE REGION IS TSAT
C
      T1 = TIN
      IF(H(1) .GT. CRIT ) GO TO 510
       INN = NDP(INODE)
      DO 511 I=1,INN
      TLIQ(I) = T1 + QO(INODE,I)*PH(INODE)*(DZ(INODE,I)/2.)
     1           /(CPF*GO(INODE)*AXS(INODE))
      TWALL(I) = TLIQ(I) + QO(INODE,I)/HO(INODE)
      T1 = TLIQ(I)
  511 CONTINUE
C
  510 DO 520 I=INN1,NP1
      TLIQ(I) = TSATP
       IF(IOSUB .EQ. 0) GO TO 1003
       IF(IOSUB .EQ. 1 .AND. I .LT. NBB1(INODE)) GO TO 521
       GO TO 1003
  521 CONTINUE
      TL=TSATP-(ENTHP-AVGH(I))/CPF
      TLIQ(I) = TL
 1003 TWALL(I) = TSATP + (QO(INODE,I)/CKI)**(1./CMP)
C     V22(INODE,I) = CKI*CMP*(TWALL(I)-TSATP)**(CMP-1.)
  520 CONTINUE
C
      VEX = JOIN(NP1) + DZ(INODE,NP1)*K1(INODE,NP1)
  604 ALFSUM = 0.
      DO 530 I=INN1,NP1
  530 ALFSUM = ALFSUM + ALFNOD(INODE,I)*DZ(INODE,I)
      CHALF = ALFSUM/ALHEAT
C
C     * CHECK NODES WHICH INCLUDE SPACER
C         NUMBSP(I,J) ; THE NUMBER OF SPACERS INTHE (I,J)-TH NODE
C
      DO 550 I=1,NP1
      NUMBSP(INODE,I) = 0
  550 CONTINUE
C
      IF(NSP .EQ. 0) GO TO 600
      KSP = 1
      I = 0
  551 I = I + 1
      IF(I .GT. NP1) GO TO 552
      IF(ZSP(KSP) - Z(INODE,I) .GT. 1.0E-03) GO TO 551
  553 NUMBSP(INODE,I) = NUMBSP(INODE,I) + 1
      KSP = KSP + 1
      IF(KSP .GT. NSP) GO TO 552
      IF(ZSP(KSP) .GT. Z(INODE,I)) GO TO 551
      GO TO 553
  552 CONTINUE
C
C    * PARAMTERS TO CALCULATE THE LOCAL PRESSURE DROP IN THE SINGLE-
C                & THE TWO-PHASE REGION
C        N1PSP(I) ; THE TOTAL NUMBER OF SPCERS IN THE SINGLE-PHASE REGION
      N1PSP(INODE) = 0
       IF(ISUB(INODE) .GT. 0) GO TO 560
      DO 561 I=1,INN
  561 N1PSP(INODE) = N1PSP(INODE) + NUMBSP(INODE,I)
  560 K2PSP(INODE) = N1PSP(INODE) + 1
C
      K2HSP = N1PSP(INODE) + 1
      DO 570 K=INN1,NP1
      KK = K - 1
      NNSP = NUMBSP(INODE,K)
      IF(NNSP .EQ. 0) GO TO 570
      IF(ISUB(INODE) .GT. 0 .AND. K .EQ. INN1) GO TO 571
      DO 572 N=1,NNSP
      DELSZ = ZSP(K2HSP) - Z(INODE,KK)
      CKSP(K2HSP) = CKIN(INODE,K) + DELSZ*COH(INODE,K)*K1(INODE,K)
      ZETSP(INODE,K2HSP) = CKSP(K2HSP) / CKIN(INODE,K)
  572 K2HSP = K2HSP + 1
      GO TO 570
C
  571 DO 573 N=1,NNSP
      CKSP(K2HSP) = CKIN(INODE,K) + ZSP(K2HSP)*COH(INODE,K)*K1(INODE,K)
      ZETSP(INODE,K2HSP) = CKSP(K2HSP) / CKIN(INODE,K)
  573 K2HSP = K2HSP + 1
  570 CONTINUE
C
C    * CALCULATE STEADY-STATE PRESSURE DROPS . . . . . . . . . . . .
C                        ACCL   FRIC    GRAV    LOCAL  SPACER   TOTAL
C     1) SINGLE-PHASE;         DPH1PF  DPH1PG    DPIN  DP1HSP   DP1HP
C     2) TWO-PH.(NODE);DPH2PA  DPH2PF  DPH2PG  DPEXIT    DPSP
C        TWO-PH.(TOTAL); DP2A   DP2F     DP2G          DP2HSP    DP2T
C
C    * 1) SINGLE-PHASE REGION
  600 DPIN = XKIN(INODE)*GO2RF(INODE)
      DP1HSP = DPIN
      DPH1P = 0.
      DPH1PG = 0.
      DPH1PF = 0.
      IF(ISUB(INODE) .GT. 0) GO TO 701
      INNSP = N1PSP(INODE)
      IF(INNSP .EQ. 0) GO TO 605
      DO 700 I=1,INNSP
      DPSP(I) = KLOSS(I)*GO2RF(INODE)
      DP1HSP = DP1HSP + DPSP(I)
  700 CONTINUE
C
  605 DPH1PG = DENSF*CHLAMB(INODE)*G1/GC
      DPH1PF = FRICMO(INODE)*CHLAMB(INODE)*GO2RF(INODE)/DH(INODE)
      DPH1P = DPH1PG + DPH1PF
C    * 2) TWO-PHASE REGION
  701 DP2G = 0.
      DP2F = 0.
      DP2A = 0.
      DP2T = 0.
      DO 710 I=INN1,NP1
      IF(ZETA(INODE,I)-1. .LE. 1.0E-04) GO TO 702
      C19 = (G1/GC)*DZ(INODE,I)*DENSF*(1.-1./COH(INODE,I))
      C20 = (G1/GC)*(CKIN(INODE,I)/COH(INODE,I)/K1(INODE,I))*(DENSI/
     1         COH(INODE,I)-C4*ALPIN(INODE,I))
      DPH2PG(I) = (C19 + C20*ALOG(ZETA(INODE,I)))
      GO TO 703
  702 DINO = DENSF-C4*ALPIN(INODE,I)
      DPH2PG(I) = DINO*DZ(INODE,I)*G1/GC
  703 DP2G = DP2G + DPH2PG(I)
      DPH2PF(I) = V7(INODE)*DZ(INODE,I)*COR2PH(INODE,I)
      DP2F = DP2F + DPH2PF(I)
      IF(I .EQ. INN1) GO TO 711
      II = I - 1
      RHOIN = (1.-XEXIT(II))**2/((1.-ALPIN(INODE,I))*DENSF) +
     1         XEXIT(II)**2/(RHOG*ALPIN(INODE,I))
      GO TO 712
  711 RHOIN = 1./DENSF
  712 RHOOUT = (1.-XEXIT(I))**2/((1.-ALPOUT(I))*DENSF) + XEXIT(I)**2
     1          /(RHOG*ALPOUT(I))
      DPH2PA(I) = (GO2(INODE)/GC)*(RHOOUT - RHOIN)
      DP2A = DP2A + DPH2PA(I)
      DPH2P(I) = DPH2PG(I) + DPH2PF(I) + DPH2PA(I)
      DP2T = DP2T + DPH2P(I)
  710 CONTINUE
C
      DP2HSP = 0.
      KNSP = N1PSP(INODE)
      DO 720 I=INN1,NP1
      II = NUMBSP(INODE,I)
      IF(II .EQ. 0) GO TO 720
      DO 721 K=1,II
      KNSP = KNSP + 1
      DPSP(KNSP) = (KLOSS(KNSP)*GO2(INODE)/(2.*GC*DENSF)) *
     1                COR2PH(INODE,I)
  721 DP2HSP = DP2HSP + DPSP(KNSP)
  720 CONTINUE
      DPEXIT = XKEXIT(INODE)*GO2(INODE)/(2.*GC*DENSF)*COR2PH(INODE,NP1)
      DP2HSP = DP2HSP+DPEXIT
C
      DPHT = DPH1P + DP2T
      DPTS = DP1HSP+ DPHT + DP2HSP
      IF(IRW .EQ. 0) GO TO 800
      IF(IWIT .LE. 1) GO TO 4000
C
C ***** PRINT OUT FOR CHANNEL CHARECTERISTICS IN STEADY-STATE *****
C
  800 IF(ICH.NE.3 .AND. ICH.NE.6) GO TO 802
      WRITE(6,11)INODE,AXS(INODE),PH(INODE),DH(INODE),BBLAMB(INODE),
     1 CXF(INODE),VIN(INODE),XKIN(INODE),XKEXIT(INODE),RPWR(INODE)
      IF(ICAL .LE. 1) GO TO 801
      IF(ICAL .EQ. 4) GO TO 801
C
  801 WRITE(6,41)
      IF(IOHW .EQ. 0) WRITE(6,43)
      IF(IOHW .EQ. 1) WRITE(6,45) CPH, DENSH
      IF(IOHW .EQ. 2) WRITE(6,47) CPH, TKH, DENSH
      IF(IOHW .EQ. 3) WRITE(6,49) CPH, TKH, DENSH, CRI, CRO
      IF(IOHW .EQ. 4) WRITE(6,51) CPH,TKH,DENSH,CRS, CPC,TKC,
     1                               DENSC,CRI,CRO, GAPC
  802 IF(ICH.NE.4 .AND. ICH.NE.6) GO TO 821
C
      WRITE(6,57)
      DO 820 I=1,NP1
      IF(I .EQ. INN1) WRITE(6,59)
  820 WRITE(6,61)I,Z(INODE,I),QO(INODE,I),QDIS(INODE,I),TLIQ(I),
     8              TWALL(I)
  821 IF(ICH.LE.1 .OR. ICH.EQ.3) GO TO 831
C
      IF(NODES .EQ. 1) GO TO 831
      WRITE(6,67)
      DO 830 I=INN1,NP1
      WRITE(6,69) I,DZ(INODE,I),K1(INODE,I),COH(INODE,I),VGJH(INODE,I),
     1             ALFNOD(INODE,I),XEXIT(I),AVGH(I), JOIN(I)
  830 CONTINUE
  831 IF(ICH.EQ.0 .OR. ICH.EQ.2 .OR. ICH.EQ.3) GO TO 4000
      WRITE(6,71)
      ZIN = 0.0000
      WRITE(6,73) ZIN, XKIN(INODE), DPIN
      DO 840 I=1,NSP
      WRITE(6,73) ZSP(I), KLOSS(I), DPSP(I)
  840 CONTINUE
      WRITE(6,73) ALHEAT, XKEXIT(INODE), DPEXIT
C
      IF(H(1) .GT. CRIT) GO TO 850
      WRITE(6,75) DP1HSP,DPH1PG,DPH1PF,DPH1P
  850 WRITE(6,77)
      DO 860 I=INN1,NP1
      WRITE(6,79) I, Z(INODE,I), DPH2PG(I),DPH2PF(I),COR2PH(INODE,I),
     1             DPH2PA(I), DPH2P(I)
  860 CONTINUE
      WRITE(6,81) DP2G, DP2F, DP2A, DP2T, DP2HSP, DPTS
      GO TO 4000
C
 2000 WRITE(6,85)
      STOP
C
 4000 RETURN
      END
C
C
C
C
C***********************************************************************
      SUBROUTINE XLOOP(ICAL,JLL,JRR,IPUMP,IRSLIP)
C***********************************************************************
C
C    * CALCULATE THE STEADY-STATE PARAMETERS OF THE LOOP ANALYSIS
C
      REAL MUTL, KF, KLOSS
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMPLEX CL1X,RR4
      COMPLEX CSBX3, DGAMP,VPL
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
      COMMON/OPTION/ IOSUB, IOHW, IO2Q, IPILO, ISLIP, IRW
      COMMON/CONST1/ C1(200),C2(200),C3(200),C4,C5(200),C8(200,30),
     1        C9(200,30),C18(200), C21(200), C22(200),C25(200),
     2        C26(200), I6, V7(200), DD1, CKI, CMP
      COMMON/CONST2/ P,VCH,VIN(200),AXS(200),DH(200),DHIN(200).
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     1        PH(200),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2        DENSF,VFG1,RHOG,GO(200),GO2(200),HO(200),GC,G1,KLOSS(30),
     3        FRICMO(200),VGJH(200,30),COH(200,30),CZERO,VGJ,DPTS,
     4        GO2RF(200),HFG1,ZSP(30),NUMBSP(200,30),ALHEAT,CXF(200),
     5        AVEQ,CHOMO1,CHOMO2,XKIN(200),XKEXIT(200)
      COMMON/CONSS1/ QDIS(200,30), QO(200,30), DZ(200,30),Z(200,30),
     1        K1(200,30), CKIN(200,30), ZETA(200,30), DOIN(200,30),
     2        DOOUT(200,30), ALPIN(200,30),BEE(200,30), CPI1(200,30),
     3        COR2PH(200,30), ZETSP(200,30), WIN
      COMMON/PCHOUT/XCHOUT(200), ACHOUT(200), CCHOUT(200)
      COMMON/CONSS2/ NTOT(200),NBB(200),NBB1(200),NSP,N1PSP(200),
     1               K2PSP(200), NDP(200), NDP1(200), ISUB(200)
      COMMON /RISER/ COR,VGJR,CKRO,RL,AR,DRIN,DR,PI,CL1,CL2,CL3,CL4,
     1        CL5,CL6,CR5,CR6,UPJ1(200),UPJ2(200),RO11,RO12,
     2               RO21, RO22, XROUT, UPJIN
      COMMON/CLOOP/SLOOP,SFLOOP,RLOOP,AA,
     @                 VL1(200), VL2(200), VL3(200), DPLPT,RATW
      COMMON/CUPPER/RKIN,RKEXIT,AP,RPO,RP1,RP2,CL10(200),CL11(200),
     1               CLT,AXSCH,RAR,AD,DL,DHDL,FDL, F1(200),F2(200),
     2               RJ1(200),RJ2(200),RJ3(200),F3(200)
      COMMON /CDELH1/ HFW, ADC, PHV, DKV, CPV, DENV, TEMV, TEMINV,
     1               THV, HOD, PLM, AHLP, THLP, HOLP, WO, DLENG
      COMMON /CDELH2/ CH1, CH2, CH3, CH4, CH5, CH7, CH8, CH9, CH10
C     COMMON /XVXV/ XVL1,XVL2,XVL3
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMMON/RISERP/CLTX,RR4,CRP5,CRP8,RO13,RO23,CL12,UPJ3,ALPRO
     1               ,GOR,RHOR,VRO,CRCON,UPALP
      COMMON/SWITCH/IDCZC, IDVGJC, IDCZR, IDVGJR
      COMMON/PXX/PXEXT(200,30)
      COMMON/PSP/CSBX3(200,30),ALOUT(200,30)
      COMMON/YYY/ZLUP,FLUP,GOU,DHUP,ROUP,FUP,ZLR,FLR,ROR,FRR
     @            ,ADLP,DHLP,ZLLP,FLLP,XKLP,GOLP,FLP
     @            ,AD1,DH1,ZL1,FL1,XK1,GO1,FD1
     @            ,AD2,DH2,ZL2,FL2,XK2,GOD2,FD2
     @            ,AD3,DH3,ZL3,FL3,XK3,GO3,FD3
     @            ,SPUMP,CPUMP
      COMMON/SEPA/XINER,XLSEP,XKSEP,XASEP,XRHOS,ALPSEP,GOSEP,
     @              YLSEP,DHSEP,FSEP,CSEP,VSEP,CORPR
      COMMON/DELTAP/DGAMP,DRHOG,DHF,DHG,DCZERO,DVGJ,DCOR,DVGJR
      COMMON/PIV/IV
      COMMON/VV4/PL1,PL2,PL4
      COMMON/VV5/VPL
      COMMON/PGAM/IGAM,IDRF
      COMMON/PCO/ICO
      COMMON/RNEW/F3P,RJ3P
      COMMON/MULT/NN(200)
      COMMON/MULTW/UPJW(200),CLW(200),PJOUT(200)
      COMMON/PBB/POWER,BYPOWF,BYFLWF
C   QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
   15 FORMAT(//5X,'PARAMETERS FOR THE UPPER PLENUM',//10X,
     1  'FLOW AREA',6X,'LENGTH I', 6X,'LENGTH II', 6X,
     2  'CURVATURE',6X,'HYDR. DIAM.')
   17 FORMAT(/9X, F9.4, 4(6X,F9.4) )
   19 FORMAT(/10X,'VOID FRACTION =',E10.4, 'VO,UP =',E10.4 )
   21 FORMAT(//5X,'PARAMETERS FOR THE RISER', //10X,' LENGTH  ',
     1        6X,'FLOW AREA', 5X,'HYDR.DIAM.', 9X,'CO', 12X,'VGJ')
   23 FORMAT(/9X,F9.4, 4(6X,F9.4) )
   25 FORMAT(/10X,'GO,R =',E10.4, 5X,'VO,R =',E10.4, 5X,
     1        'VOID FRACTION =',E10.4, /10X,'CORPR =',E10.4 )
   27 FORMAT(//5X,'PARAMETERS FOR THE LOOP',  //10X,'  SLOOP  ',
     1        8X,'SFLOOP', 11X,'AA')
   29 FORMAT(/4X, 2(5X,E10.4), 5X,E10.4)
   31 FORMAT(//5X,'PARAMETERS FOR DOWNCOMER ENTHALPY DYNAMICS',//,
     1 7X,'F.W. ENTH',6X,'FLOW AREA',7X,'LENGTH',15X,'VESSEL TEMPS',
     2          15X,'PH',         13X,'HO' )
   33 FORMAT(/2X, 7(5X,E10.4) )
   35 FORMAT(//20X,'VESSL WALL', /20X,'THICKNESS(FT)  =',3X,E10.4,
     1          /20X,'THERMAL CONDUTIVITY  =',3X,E10.4,
     2          /20X,'SPECIFIC HEAT  =',3X,E10.4,
     3          /20X,'DENSITY(LB/FT3)  =',3X,E10.4)
   37 FORMAT(/10X,'WO(LB/S)  =',3X,E10.4,10X,'ENTH. MIX.=',3X,E10.4,
     1          10X,'ENTH. DC(EXIT)  =',3X,E10.4)
   39 FORMAT(//5X,'PARAMETERS FOR LOWER PLENUM',//7X,'COOLANT MASS
     1 (LB)',1X,'H/T AREA', 10X,'HO', 10X,'THICK',9X,'HEAT FLUX')
C
C     * CALCULATE THE INLET PARAMETERS OF THE UPPER PLENUM
C         XUPI ; INLET FLOW QUALITY
C         UPALP ; INLET VOID FRACTION
C         UPJIN ; INLET FLOW VELOCITY
C
      DRF=DRFDP(P)
      IF(IDRF .EQ. 0)DRF=0.
      DDR=DRHOG-DRF
      DRGFP=DRHOG-RHOG/DENSF*DRF
      B10 = 0.
      DO 10 I=JLL,JRR
      B10 = B10 + XCHOUT(I)*GO(I)*AXS(I)*NN(I)
   10 CONTINUE
      WBYP=BYFLWF*WO
      SUBC=HF(P)-ENTHT
      XUPI = B10/WO-(WBYP*SUBC-BYPOWF*POWER)/(HFG1*WO)
      UPALP = XUPI*DENSF/(RHOG+C4*XUPI)
      P2 = DENSF - C4*UPALP
      UPJIN = WO/AP/P2
      UPJOUT = (AP/RAR)*UPJIN
      F = DENSF*RHOG/(RHOG+C4*XUPI)**2
      GOP = UPJIN*P2
      SUMF3P=0.
      SUMJ3P=0.
      SUMI=0.
      SUMI2=0.
      DO 11 I=JLL,JRR
      NP1 = NTOT(I)
      E1 = -RHOG*VGJH(I,NP1)*DENSF*ACHOUT(I)/GO(I)**2
      E2 = (RHOG*COH(I,NP1)/DENSF + RHOG*VGJH(I,NP1)/GO(I) +
     1      C4*COH(I,NP1)*XCHOUT(I)/DENSF + C4*RHOG*VGJH(I,NP1)*
     2      ACHOUT(I)*CCHOUT(I)/GO(I)**2) / (1.-C4*COH(I,NP1)*
     3      ACHOUT(I)/DENSF)
       F1(I) = F*AXS(I)*GO(I)*E1/WO
       F2(I) = F*AXS(I)*GO(I)*E2/WO
       F3(I) = F*(XCHOUT(I)-XUPI) /WO
       RJ1(I)=(C4*UPJIN*F1(I)+AXS(I)*(DENSF-C4*COH(I,NP1)*ACHOUT(I))
     1          /AP) / P2
       RJ2(I) = (C4*UPJIN*F2(I)-AXS(I)*C4*CCHOUT(I)/AP) / P2
       RJ3(I) = C4*UPJIN*F3(I) / P2
      WW=GO(I)*AXS(I)/WO
      CZERO=COH(I,NP1)
      VGJ=VGJH(I,NP1)
      P1=CZERO*RHOG/DENSF+RHOG*VGJ/GO(I)
      CL7 = P1 + CZERO*C4*XCHOUT(I)/DENSF
     1 + (C4*RHOG*VGJ/G0(I)**2)*ACHOUT(I)*CCHOUT(I)
      CL8 = (RHOG + C4*XCHOUT(I)) /DENSF
      CL9 = P2 / (DENSF-CZERO*C4*ACHOUT(I))
      CL10(I) = (CL7/CL8) * CL9*WW
      CL11(I) = -(VGJ*RHOG*DENSF*ACHOUT(I)*(P2/DENSF)) /
     1          (CL8*G0(I)**2)*WW
      CLW(I)=(XCHOUT(I)-XUPI)/(WO*(CL8*DENSF/P2))
      UPJW(I)=C4*UPJIN*CLW(I)/P2
      UPJ1(I) = ((AXS(I)/AP)*(DENSF-C4*CZERO*ACHOUT(I))
     1               + C4*UPJIN*CL11(I)) /P2
      UPJ2(I) = (C4*UPJIN*CL10(I)- (AXS(I)/AP)*C4*CCHOUT(I)) / P2
C ADD J3 AND F3 TO CODE
      PJOUT(I)=(CCHOUT(I)-VGJ)/CZERO
      CP3=ACHOUT(I)*RHOG/G0(I)*(1+ACHOUT(I)*C4*VGJ
     1    /G0(I))*DVGJ
      CP3=CP3+ACHOUT(I)*CZERO/DENSF*DRF*(XCHOUT(I)-RHOG/DENSF)
      CP2=ACHOUT(I)/DENSF*(RHOG+XCHOUT(I)*C4+ACHOUT(I)*PJOUT(I)
     1    *RHOG*DENSF*C4*VGJ/G0(I)**2)*DCZERO
      CP1=ACHOUT(I)*(CZERO/DENSF*(XCHOUT(I)-1)
     1    -VGJ/G0(I)*(1-RHOG*ACHOUT(I)*CCHOUT(I)
     2     /G0(I))]*DRHOG
      CL12=-(CP1-CP2-CP3)*DENSF/P2
      SUM12=SUM12+CL12*WW*NN(I)
      UPJ32=AXS(I)/AP*(ACHOUT(I)*CCHOUT(I)*DDR-ACHOUT(I)*C4*
     @       (DCZERO*PJOUT(I)+DVGJ)+PJOUT(I)*DRF)
      SUM1=SUM1+UPJ32*NN(I)
      UPJ31=DDR*UPALP*UPJIN+DRF*UPJIN
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
   11 CONTINUE
      CP4=-(UPALP*DRHOG/DENSF*(XUPI-1.)-UPALP/DENSF*DRF*(XUPI-
     @       RHOG/DENSF))*DENSF/P2
      CL12=SUM12-CP4/(CL8*DENSF/P2)
      UPJ33=C4*UPJIN*CL12
      UPJ3=(UPJ33+SUM1-UPJ31)/P2
C
      DRP = RP2 - RP1
      CLTX = 0.
      IF(RPO .EQ. 0.) GO TO 12
      CLTX = AP*DRP + (PI*RPO-AP/RPO)*(RP2**2-RP1**2)/2.
     1               - PI*(RP2**3-RP1**3)/3.
   12 CLT = (RP1 - ALHEAT + CLTX/AP) /UPJIN
C
C     INLET PARAMETERS IN THE RISER
C
      IF(IRSLIP .NE. 0)GO TO 77
      TAVE=(TIN+TSATP)/2.
      SIGMA=SGMA(P,TAVE)
      COR=1.2-0.2*SQRT(RHOG/DENSF)
      VGJR=2.9*(C4*SIGMA*G1*32.2/DENSF**2)**.25
   77 WRITE(6,52)COR,VGJR
   52 FORMAT(//'CO,VGJ IN RISER',2X,2(E10.4,2X))
      GOR = (AP/RAR)*GOP
      XROUT = XUPI
      ALPRO = XROUT/(RHOG*VGJR/GOR+COR*RHOG/DENSF*(1.+XROUT
     @        *C4/RHOG))
      CL2 = DENSF - C4*COR*ALPRO
      VRO = (GOR+C4*VGJR*ALPRO)/(DENSF-C4*COR*ALPRO)
      CKRO=COR*VRO+VGJR
      IF(IPILO .EQ. 0) GO TO 13
      RPI1 = DD1*XROUT**(-0.176)/(VFG1*DENSF)
      RPI2 = 1.
      GO TO 14
   13 RPI1 = CHOMO1
      RPI2 = CHOMO2
   14 CORPR = RPI2 + RPI1*VFG1*DENSF*XROUT
      RHOR = DENSF - C4*ALPRO
      DR = DRIN/12.0
      C1R = -1.41E-05*DRIN + 3.36E-04
      VISR = MUTL(TSATP)/3600.0
      RER = GOR*DR/VISR
      FRICR = 0.0055*(1. + (20000.*C1R+1.0E+06/RER)**(1./3.))
      RC1 = (RHOG + C4*XUP1) / P2
      RC2 = COR*RHOG/DENSF + RHOG*VGJR/GOR + COR*C4*XROUT/DENSF
     1      + C4*RHOG*VGJR*ALPRO*CKRO/GOR**2
      RC3 = RC2 / (CL2/DENSF)
      RC4 = -RHOG*DENSF*VGJR*ALPRO/GOR**2
      ROD = C4*CKRO*RC4 + CL2*RC3
      RO11 = (P2*RC3/ROD) * (AP/RAR)
      RO12 = (C4*CKRO*RC1 - C4*UPJOUT*RC3) / ROD
      RO21 = -(P2*RC4/ROD) * (AP/RAR)
      RO22 = (C4*UPJOUT*RC4 + CL2*RC1) / ROD
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      CL1 = (FRICR*GOR*CORPR) / (GC*DENSF*DR)
      CL3 = (FRICR*GOR/(2.*GC*DR)) * (1.-VRO*CL2/GOR) *  RPI1
      CL4 = - (FRICR*VRO*C4*CKRO**2) / (2.*GC*DR) * RPI1
      CL5 = -2.*(GOR/RHOR)*C4*CKRO + C4*(GOR/RHOR)**2
      CXX = DENSF*RHOG * ((COR-1.)*VRO+VGJR)**2
     1        /  (RHOR**2 - RHOG*RHOR)**2
      CL6 = CXX * (2.*DENSF*RHOR - RHOR**2 - RHOG*DENSF) * C4
      CRCON = (GOR*CORPR/DENSF - RPI1*VRO/2.) / GC
      CR5 = CRCON*CL2 + GOR*RPI1/(2.*GC)
      CR6 = -C4*CKRO*CRCON
C     WRITE(10,1983)RC4,RC2,CL2,ALPRO,GOR
C     WRITE(10,1983)CR6,CRCON,CORPR,RPI1
 1983 FORMAT('YNIRET LINE',2X,10(E10.4,1X))
      CH1 = -RAR/VFG1 + (RAR*DENSF/C4)*CL2
      CH2 = RAR*CKRO*DENSF
      WSWO = WO*(1.-XROUT)
      CH9 = FDL*WSWO**2/(2.*GC*DHDL*AD**2*DENSF) - (G1/GC)*DENSF
      CH10 = DL*FDL*WSWO/(GC*DHDL*AD**2*DENSF)
C
C      3) FOR THE SINLE-PHASE LOOP
C
      XVL1 = SLOOP/GC * RATW
      XVL2 = (WO/DENSF)*SFLOOP / GC * RATW
      XVL3 = AA * RATW
C
C    * CALCULATE THE S.S PRESSURE DROP IN THE EXT. LOOP
C
C      1) FOR THE UPPER PLENUM
          DPUPL = (G1/GC)*P2*(RP2-ALHEAT)
C      2) FOR THE RISER
          DPR =((RHOR+CL1*GOR/2.)*(RL-RP2)*G1/GC+(RKIN+RKEXIT)*
     1               GOR**2*CORPR/(2.*GC*DENSF) )
C      3) FOR THE LOOP
          DPLOOP = SFLOOP*(WO**2/2./GC/DENSF)
C      * TOTAL P.D. IN THE EXT; LOOP
          DPLPT = DPUPL + DPR + DPLOOP
```

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C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C    * II) EXTERNAL LOOP
C    *  1) UPPER PLENUM I & II
      WCORE=WO
      ROUP=DENSF*(1.-UPALP)+RHOG*UPALP
      GOU=ROUP*UPJIN
      DHUP=SQRT(4.*AP/3.1416)
      XU=-1.41E-05*DHUP*12.+3.36E-04
      YU=GOU*DHUP/VISC
      FUP=.184/(2.*DHUP*YU**0.2)
      DPUF=GOU**2/(2.*GC*ROUP)*FLUP/DHUP*FUP
      DPUG=G1/GC*ROUP*(ZLUP+DRP)
      SIGUP=AP/AR
C     DPUL=-(1.-SIGUP**2-SIGUP**2*RKIN)*GOU**2/(2.*ROUP*GC)
      DPUL=0.
      DPU=DPUF+DPUG+DPUL
      WRITE(6,84)DPUF,DPUG,DPUL,DPU
C    *  2) RISER
      ROR=DENSF*(1.-ALPRO)+RHOG*ALPRO
      XR=-1.41E-05*DRIN+3.36E-04
      YR=GOR*DRIN/12./VISC
      FRR=.184/(2.*DR*YR**0.2)
      DPRF=GOR**2/(2.*GC*ROR)*FLR/(DRIN/12.)*FRR
      DPRG=G1/GC*ROR*ZLR
      DPRL=RKEXIT*GOR**2/(2.*GC*ROR)
      DPR=DPRF+DPRG+DPRL
C    *  3) STEAM SEPARATOR
      XRHOS=RHOR
      ALPSEP=ALPRO
      GOSEP=GOR
      FSEP=FRR
      VSEP=VRO
      XS=-1.41E-05*DHSEP+3.36E-04
      YS=GOSEP*DHSEP/VISC
      FSS=.184/(2.*DHSEP*YS**0.2)
      DPSF=GOSEP**2/(2.*GC*XRHOS)*XLSEP/(DHSEP)*FSS
      DPSG=G1/GC*XRHOS*XLSEP
      DPSL=XKSEP*GOSEP**2/(2.*GC*XRHOS)
      DPS=DPSF+DPSG+DPSL
C    *  4) REGION D1
C     THEPOW=1948.
      HGPP=HF(P)+HFG(P)
C     WST=(3.1412*THEPOW-.033*HGPP+16.2)/(HGPP-HFW)*1.E+06+33000.
C     WST=WST/3600.
      WST=WO*XROUT
      G01=(WCORE-WST)/AD1
      X1=-1.41E-05*DH1*12.+3.36E-04
      Y1=G01*DH1/VISC
      FD1=.184/(2.*DH1*Y1**0.2)
      DP1F=G01**2/(2.*GC*DENSF)*FL1/DH1*FD1
      DP1G=-G1/GC*DENSF*ZL1
      DP1L=XK1*G01**2/(2.*GC*DENSF)
      DP1=DP1F+DP1G+DP1L
C    *  5) REGION D2
      WIW=WST
      GOD2=WCORE/AD2
      X2=-1.41E-05*DH2*12.+3.36E-04
      Y2=GOD2*DH2/VISC
      FD2=.184/(2.*DH2*Y2**0.2)
      DPTF=GOD2**2/(2.*GC*DENSF)*FL2/DH2*FD2
      DPTG=-G1/GC*DENSF*ZL2
      DPTL=XK2*GOD2**2/(2.*GC*DENSF)
      DP2=DPTF+DPTG+DPTL
C     *  6) REGION D3
      GO3=WCORE/AD3
      X3=-1.41E-05*DH3*12.+3.36E-04
      Y3=GO3*DH3/VISC
      FD3=.184/(2.*DH3*Y3**0.2)
      DP3F=GO3**2/(2.*GC*DENSF)*FL3/DH3*FD3
      DP3G=-G1/GC*DENSF*ZL3
      DP3L=XK3*GO3**2/(2.*GC*DENSF)
      DP3T=DP3F+DP3G+DP3L
C     *  7) LOWER PLENUM
      GOLP=WCORE/ADLP
      XLP=-1.41E-05*DHLP*12.+3.36E-04
      YLP=GOLP*DHLP/VISC
      FLP=.184/(2.*DHLP*YLP**0.2)
      DPLPF=GOLP**2/(2.*GC*DENSF)*FLLP/DHLP*FLP
      DPLPG=G1/GC*DENSF*ZLLP
      DPLPL=XKLP*GOLP**2/(2.*GC*DENSF)
      DPLP=DPLPF+DPLPG+DPLPL
C     * III) TOTAL EXTERNAL LOOP PRESSURE DROP(EXCLUDING PUMP)
      DPLOOP=DPU+DPR+DPS+DP1+DP2+DP3T+DPLP
C     *  8) REGION D3(PUMP)
      PFW=WCORE*3600./1.E+06
      PA=0.
      PB=0.
      DP3=DPTS+DPLOOP
      IF(IPUMP .NE. 0)DPX=DP3
C
      CALL PUMP(IPUMP,SPUMP,AA,DPX,PFW,DENSI,G1,GC)
C
      CPUMP=SPUMP*100.
      DPLPT=DPLOOP
      IF(IV .EQ. 0)GO TO 79
      SLOOP=FL1/AD1+FL2/AD2+FL3/AD3+FLLP/ADLP
      SFLOOP=(FD1*FL1/DH1+XK1)/AD1**2+(FD2*FL2/DH2+XK2)/AD2**2+
     @  (FD3*FL3/DH3+XK3)/AD3**2+(FLP*FLLP/DHLP+XKLP)/ADLP**2
   79 CONTINUE
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
C
C     * CALCULATE THE PARAMETERS FOR THE DELHI
C
      IF(ICAL .EQ. 3 .OR. ICAL .EQ. 5) GO TO 102
      GO TO 100
  102 CH3 = (PHV*HOD/WO/CPF) / (1.+THV*HOD/DKV)
      CH4 = (ENTHP-HFW) * (XROUT*WO/WO**2)
      CH5 = HOD/(1.+THV*HOD/DKV) * (TEMINV - TEMV)
      CH6 = (1.-XROUT)*ENTHP + XROUT*HFW
      CHH = -CH3*DLENG
      CH7 = (PHV*CH5/WO/CH3) * (EXP(CHH)-1.) + CH6
      CH8 = HOLP*(TIN-TEMV) / (1.+HOLP*THLP/DKV)
C
  100 WRITE(6,15)
      WRP1=RP1-ALHEAT
      WRP2=RP2-RP1
      WRL=RL-RP2
      WRITE(6,17) AP,WRP1,WRP2, RPO,DHUP
      WRITE(6,19) UPALP, UPJIN
      WRITE(6,21)
      WRITE(6,23)WRL, AR, DR, COR, VGJR
      WRITE(6,25) GOR, VRO, ALPRO, CORPR
      WRITE(6,398)
      WRITE(6,397)
      WRITE(6,399)XIKER,XLSEP,XKSEP,XASEP,DHSEP
  398 FORMAT(/,5X,'PARAMETERS FOR STEAM SEPARATOR ')
  397 FORMAT(/11X,'INER',9X,'LENGTH',7X,'LOSS COEF.',4X,
     @       'FLOW AREA',5X,'HYDR. DIAM.')
  399 FORMAT(/,8X,4(E12.4,2X),E12.4)
      WRITE(6,27)
      WRITE(6,29) SLOOP, SFLOOP, AA
      IF(ICAL .EQ. 3 .OR. ICAL .EQ. 5) GO TO 200
      GO TO 101
  200   WRITE(6,31)
        WRITE(6,33) HFW, ADC, DLENG, TEMV, TEMINV, PHV, HOD
        WRITE(6,35) THV, DKV, CPV, DENV
        WRITE(6,37) WO, CH6, CH7
        WRITE(6,39)
        WRITE(6,33) PLM, AHLP, HOLP, THLP, CH5
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      WRITE(6,62)
   62 FORMAT(//,'DOWNCOMER GEOMETRY')
      WRITE(6,64)
   64 FORMAT(/,18X,'LENGTH',9X,'  FLOW AREA',7X,'HYDR. DIAM.',
     @       7X,'LOSS COEF.')
      WRITE(6,65)ZL1,AD1,DH1,XK1
   65 FORMAT(/,'DOWNCOMER 1    ',3(E12.4,5X),E12.4)
      WRITE(6,66)ZL2,AD2,DH2,XK2
   66 FORMAT(/,'DOWNCOMER 2    ',3(E12.4,5X),E12.4)
      WRITE(6,67)ZL3,AD3,DH3,XK3
   67 FORMAT(/,'DOWNCOMER 3    ',3(E12.4,5X),E12.4)
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      WRITE(6,188)
  188 FORMAT(//,'PRESSURE DROPS (PSI) IN RECIRCULATION LOOP')
      WRITE(6,190)
  190 FORMAT(/,19X,'FRICTION',9X,'GRAVITY',9X,'LOCAL LOSS',9X,
     @       'TOTAL')
      WRITE(6,84)DPUF,DPUG,DPUL,DPU
   84 FORMAT(/,'UPPER PLENUM   ',2X,3(E12.4,5X),E12.4)
      WRITE(6,85)DPRF,DPRG,DPRL,DPR
   85 FORMAT(/,'RISER          ',2X,3(E12.4,5X),E12.4)
      WRITE(6,185)DPSF,DPSG,DPSL,DPS
  185 FORMAT(/,'STEAM SEPARATOR',2X,3(E12.4,5X),E12.4)
      WRITE(6,80)DP1F,DP1G,DP1L,DP1
   80 FORMAT(/,'DOWNCOMER 1    ',2X,3(E12.4,5X),E12.4)
      WRITE(6,81)DPTF,DPTG,DPTL,DP2
   81 FORMAT(/,'DOWNCOMER 2    ',2X,3(E12.4,5X),E12.4)
      WRITE(6,86)DP3F,DP3G,DP3L,DP3T
   86 FORMAT(/,'DOWNCOMER 3    ',2X,3(E12.4,5X),E12.4)
      WRITE(6,186)
  186 FORMAT('EXCLUDING PUMP')
      DPY=-DPX
      WRITE(6,983)CPUMP,DPY
  983 FORMAT(/,'PUMP           ',2X,'(PUMP SPEED ',E12.4,' % RATED)',
     @       19X,E12.4)
      WRITE(6,83)DPLPF,DPLPG,DPLPL,DPLP
   83 FORMAT(/,'LOWER PLENUM   ',2X,3(E12.4,5X),E12.4)
      TLDP=DPU+DPR+DPS+DP1+DP2+DP3T+DPY+DPLP
      WRITE(6,986)TLDP
  986 FORMAT(/;'TOTAL EXTERNAL LOOP PRESSURE DROP',35X,E12.4)
   96 FORMAT(//3X,'TOTAL PRESSURE DROP(PSI) IN HEATED CHANNEL IS
     @ ',2X,E10.4)
   97 FORMAT(3X,'TOTAL DP IN EXTERNAL LOOP EXCLUDING  PUMP IS  ',
     @  E10.4)
   98 FORMAT(3X,'PRESSURE DROP IN  PUMP (PSI) IS',
     @       2X,E10.4)
  982 FORMAT(3X,'PUMP HEAD REQUIRED(PSI) IS  ',E10.4)
   99 FORMAT(3X,'PUMP SPEED IS  ',E10.4,1X,'%  RATED SPEED')
C QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
  101 RETURN
      END
C
C
C
      SUBROUTINE PUMP(IPUMP,SPUMP,AA,DP3,PFW,DENSI,G1,GC)
      DATA A12,A11,A10,B12,B11,B10/0.,-.99,-.026,162.13,2.724,0./
      DATA A22,A21,A20,B22,B21,B20/0.,0.,-.62,0.,103.03,-1.82/
      F(C2,C1,C0)=C2*SPUMP**2+C1*SPUMP+C0
      IF(IPUMP .NE. 0)GO TO 50
      IF(SPUMP .GE. .60)GO TO 252
      PA=F(A12,A11,A10)
      IF(SPUMP .LE. 1.E-5)PA=0.0
      PB=F(B12,B11,B10)
      GO TO 54
  252 PA=F(A22,A21,A20)
      PB=F(B22,B21,B20)
   54 CONTINUE
      DP3=(PA*PFW+PB)*DENSI*G1/GC
      GO TO 56
   50 CONTINUE
      IF(DP3 .GE. 0. .AND. DP3 .LE. 1.E-5)GO TO 55
      IF(DP3 .LE. 0. )GO TO 55
      ALP=DP3/(DENSI*G1/GC)
      SPUMP=.60
      PA60=F(A12,A11,A10)
      PB60=F(B12,B11,B10)
      CDP3=(PA60*PFW+PB60)*DENSI*G1/GC
      IF(DP3 .GE. CDP3)GO TO 60
      E2=A12
      E1=A11
      E0=A10
      F2=B12
      F1=B11
      F0=B10
      GO TO 65
   60 E2=A22
      E1=A21
      E0=A20
      F2=B22
      F1=B21
      F0=B20
   65 CONTINUE
      A=E2*PFW+F2
      B=E1*PFW+F1
      C=E0*PFW+F0-ALP
      SPUMP=(-B+SQRT(B*B-4.*A*C))/(2.*A)
      GO TO 656
   55 SPUMP=0.00
  656 CONTINUE
```

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      PA=F(E2,E1,E0)
      PB=F(F2,F1,F0)
   56 CONTINUE
      AA=2./3.*PA*(DENSI*G1/GC)*3600./1.E+06
      RETURN
      END
      SUBROUTINE ASSIGN(N1, N2, X, IND, INODE, IB)
C
C     *  NODE REDISTRIBUTION
C
      DIMENSION XDZ(30), XQDIS(30), XCO(30), XVGJ(30)
      COMMON/CONSS1/ QDIS(200,30), QO(200,30), DZ(200,30),Z(200,30),
     1        KI(200,30), CKIN(200,30), ZETA(200,30), DOIN(200,30),
     2        DOOUT(200,30), ALPIN(200,30),BEE(200,30), CPI1(200,30),
     3        COR2PH(200,30), ZETSP(200,30), WIN
      COMMON/CONS12/ P,VCH,VIN(200),AXS(200),DH(200),DHIN(200),
     1        PH(200),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,XF,
     2        DENSF VFG1,RHOG,GO(200),GO2(200),HO(200),GC,G1,XLOSS(30),
     3        FRICMO(200),VGJH(200,30),COH(200,30),CZERO,VGJ,DPTS,
     4        GO2RF(200),HFG1,ZSP(30),NUMBSP(200,30),ALHEAT,CXF(200),
     5        AVEQ,CHOMO1,CHOMO2,XKIN(200),XKEXIT(200)
C
      DO 100 I=N1,N2
        XDZ(I) = DZ(INODE,I)
        XQDIS(I) = QDIS(INGDE,I)
        IF(IB .EQ. 0) GO TO 100
        XCO(I) = COH(INODE,I)
        XVGJ(I) = VGJH(INODE,I)
  100 CONTINUE
C
      NBB2 = N1 - 1
      INN1 = N1 + 1
      INN2 = N2 + 1
      NBBS = INN1 + 1
      DO 101 I=INN1,INN2
        IN = I - 1
        QDIS(INODE,I) = XQDIS(IN)
        IF(IB .EQ. 0) GO TO 103
        COH(INODE,I) = XCO(IN)
        VGJH(INODE,I) = XVGJ(IN)
  103   IF(I .EQ. INN1) GO TO 101
        DZ(INODE,I) = XDZ(IN)
  101 CONTINUE
C
      IF(IND .EQ. 0) GO TO 500
      GO TO 200
  500 IF(NBB2 .NE. 0) GO TO 200
        DZ(INODE,N1) = X
        Z(INODE,N1) = X
        DZ(INODE,INN1) = XDZ(N1) - DZ(INODE,N1)
        Z(INODE,INN1) = Z(INODE,N1) + DZ(INODE,INN1)
      GO TO 201
  200   DZ(INODE,N1) = X - Z(INODE,NBB2)
        Z(INODE,N1) = Z(INODE,NBB2) + DZ(INODE,N1)
        DZ(INODE,INN1) = XDZ(N1) - DZ(INODE,N1)
        Z(INODE,INN1) = Z(INODE,N1) + DZ(INODE,INN1)
C
  201 DO 102 I=NBBS,INN2
        IN = I- 1
        Z(INODE,I) = Z(INODE,IN) + DZ(INODE,I)
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  102 CONTINUE
      RETURN
      END
C
C
C
C
C********************************************************************
      SUBROUTINE PTRANS(S,IK,RATIO,AMRAT,ARRAT,NCH1,ICOUNT,IBODE,IW,
     @                  JLL,JRR,ICASE)
C********************************************************************
C
C    * CALCULATE THE OPEN-LOOP TRANSFER FUNCTION,  GH(S)
C               *  RATION   =  GH(S)
C               *  AMRAT    =  ABS(GH(S))
C               *  ARRAT    =  ANG(GH(S))
C
      COMPLEX S,ZPK,RATIO,GAM1,GAM2,GAM3,PI1,PI2,PI3,TAU1,TAU2,TAU3
      COMPLEX F1,TGAM1,TPI1,FALF,AAA,F22,ZPKP,ZPK1,RATIO1
      COMPLEX CXL,CST1,CST2,CST3,RR1,RR2,RR3,DPUP1,DPUP2,DPUP3,
     1          DWSW1,DWSW2,DWSW3,T1,DPH1
      COMPLEX RAN1,GANM,ZN1,B1,RK1,XZN1,XBM,XRKM
      COMPLEX TZ1,TZ2,TWO,THREE,PWW1,PWW2
      COMPLEX PKJ,PKQ,PKH,PKP,PHJ1,SHJ,SHW,RATIOW,H
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMPLEX TALP2,TALP3,TALP4,TLP4,PM4,STC3,STC4,STC5,STC6,PP,
     1        SUMP,SUMP1,SUMSP,TEMPP,ASTAR,CSTAR,TLP,GAM2Q,HSQ
     2        ,PI2Q,T2Q,TALP1,GAM4,PI4,DWSW4,DPUP4,TSUM2,TP1
      COMPLEX GPI1,GPI2,GPI3,GPI4,QL1,QL2,QL3,QL4,QL2S,QL3S,QL4S,
     @        VJ1,VJ2,VJ3,WW1,WW2,WW1S,WW2S,HIN1S,HIN2S,BSTAR,
     @        QSTAR,SUM22S,SUM1,SUM21,SUM22,SUM42S,SUM3,SUM41,
     @        SUM42,SUMSPN,SUMP1N,SUMM
      COMPLEX GKJ,GKQ,GKH,GKP,GKJN,GKQN,GKHN,GKPN,THJ,THH,THQ,
     @        SUM1S,SUM3S,OPTK,OPTH,OPTJ,CLTK,GHJ1N,GHJ1,HJ,RATIOK,
     @        HJ1,SUMJ,RATIOP,PTOJ
      COMPLEX XK,XKP,XKRA,XKPRA,SUMPQ,PSUMW(10),
     @       U1,U2,U2S,U3,U4,XIL,
     @       TIJ,TIH,TIQ,ISTAR,ZPD,SUMXX,
     @       WWW,XXX,YYY,ZZZ,FFF,WZP
C   PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      DIMENSION CAL1(30), CAL2(30),W(10,30),PHI(10,30),DELT(5,5)
C
      COMMON /PERT/ DELVI, DELQO, DELK,DELP
      COMMON/PTKO/ZPK, ZPK1, ZPKP, DRDU, VCCAL
      COMMON/PTK2/ZPD
      COMMON /CXLP/ RR1(200), RR2, RR3, DPUP1(200), DPUP2, DPUP3,
     1              DWSW1(200), DWSW2(200,30),DWSW3,T1,DPH1,DPUP4
      COMMON/CONSS2/ NTOT(200),NBB(200),NBB1(200),NSP,N1PSF(200),
     1               K2PSP(200), NDP(200), NDP1(200), ISUB(200)
      COMMON/CONSS1/ QDIS(200,30),QO(200,30),DZ(200,30),Z(200,30),
     1       K1(200,30),CKIN(200,30),ZETA(200,30),DOIN(200,30),
     2       DOOUT(200,30),ALPIN(200,30),  BEE(200,30),CPI1(200,30),
     3       COR2PH(200,30), ZETSP(200,30), WIN
      COMMON/CONS12/ P,VCH,VIN(200),AXS(200),DH(200),DHIN(200),
     1       PH(200),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2       DENSF,VFG1,RHOG,GO(200),GO2(200),HO(200),GC,G1,KLOSS(30),
     3       FRICMO(200),VGJH(200,30),COH(200,30),CZERO,VGJ,DPTS,
     4       GO2RF(200),HFG1,ZSP(30),NUMBSP(200,30),ALHEAT,CXF(200),
     5       AVEQ,CHOMO1,CHOMO2,XKIN(200),XKEXIT(200)
      COMMON/SIM1/IMAX,JMAX,KMAX,IPASE,ISPEC,JSPEC,INUCLR,XKEFF
      COMMON/SIM2/JMX(20),NFT(15,15,30),AL(15,15),TAL(15,15),
     1            BAL(15,15),ASRC(15,15),SRC(15,15,30),AEXP(15,15),
     2            REXP(15,15,30),AXSRC(30),XXSRC(30)
      COMMON/SIM3/JJD(15,15),DZ1(200),DZ2(200;,NF(200,30),NB(200),
     1            SC(200,30,6),XEXP(200,30),SIG1(200,30,11),
     2            CSIG1(200,30,11)
C     COMMON/KIN2/RDF(15,15),RCDF(15,15),RANOI(200,4),ADF(30),
C    1            ACDF(30),GANOM(200,30,6)
      COMMON/KIN3/RANI(200,4),GANM(200,30,6),ZNI(200,4),BI(200)
      COMMON/KIN5/RKI(200),XZNI(200,30,6),XBM(200,30),XRKM(200,30)
      COMMON /DIM1/ DELX,DELZ,CHLAMB(200),ALFNOD(200,30),BBLAMB(200)
      COMMON/VOIDPT/FALF(200,30),F1(200), TGAM1(200), TPI1(200)
      COMMON/PTK1/AAA(200)
      COMMON/TWOG2/PWW1(100,100),PWW2(100,100),TZ1(100,100),
     1              TZ2(100,100),TWO(100,100),THREE(100,100)
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
      COMMON/COREP/ STC3(30),STC4(30),STC5(30),STC6(30),PP(30),
     1              TALP2(5,30,30),TALP4(200,30),TLP4,PJ
      COMMON/STABP/ TLP,DWSW4
      COMMON/PPQQ/GAM4(200),PI4(200)
      COMMON/QQQ/Q3D(200,30)
      COMMON/MULT/NN(200)
      COMMON/SSS/GPI1(5),GPI2(5,30),GPI3(5),GPI4(5),
     @QL1(5),QL2(5,30),QL3,QL4,QL2S(5,30),QL3S(5),QL4S(5),
     @      VJ1(5),VJ2(5),VJ3(5),WW1(5),WW2,WW1S(5,5),
     @      WW2S(5),HIN1S(5),HIN2S
      COMMGN/VEL/VEL3D(200)
      COMMON/TF/RATIOP,RATIOK,OPTK,OPTH,RATIOW,OPTJ,PTOJ
      COMMON/SKIN/XK(5,30,5,30),XKP(5,30),XKRA(10,10),XKPRA(10)
      COMMON/GKIN/IKIN,IDCHTY(15,15),ITY(225),JJMX(15),JJDB(15,15),
     @            ITY8(150)
      COMMON/DPLER2/U1(5,30),U2(5,30),U2S(5,30),U3(5,30),U4(5,30),
     @              XIL(5,30)
      COMMON/POINTK/PKJ,PKQ,PKH,PKP,PHJ1,SHJ,SHW
      COMMON/HIMO/H(2,3)
      COMMON/VSOS/VOL
C  QQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQQ
C
      VOL=DELX*DELX*(DELZ*30.48)
      KMAX4=4*KMAX
      NCH=0
      DO 93 J=JLL,JRR
      NCH=NCH+NN(J)
   93 CONTINUE
      CHN=FLOAT(NCH)
      IF(ICASE.EQ.2.OR.ICASE.EQ.11) GO TO 710
      IF(ICASE.EQ.4.OR.ICASE.EQ.10) GO TO 720
      IF(ICASE.EQ.5.OR.ICASE.EQ.6.OR.ICASE.EQ.13) GO TO 730
      IF(ICASE.EQ.14.OR.ICASE.EQ.15) GO TO 730
      IF(ICASE.EQ.3.OR.ICASE.EQ.7) GO TO 740
      IF(ICASE.EQ.8) GO TO 750
C
C     * POINT KINETICS, UNIFORM(ICASE=1,9,12)
C
      GKJ=ZPK*PKJ
      GKQ=ZPK*PKQ
      GKH=ZPK*PKH
      GKP=ZPK*PKP
      GHJ1=ZPK*PHJ1
      OPTK=-(GKJ+GKQ+GKH)
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      RATIOP=GKP/(1.+OPTK)
      RATIOK=ZPK1/(1.+OPTK)
      HJ=GHJ1/(1.-(GKQ+GKH))
      OPTJ=-HJ*SHJ/WIN
      H(1,1)=-OPTJ/(1.+OPTJ)
      RATIOW=H(1,1)/SHJ*WIN
      H(1,2)=RATIOK*SHJ/WIN
      H(1,3)=(SHJ*RATIOP+SHW)/WIN*P
      H(2,1)=RATIOW/ZPK1
      H(2,2)=-RATIOK*OPTK/ZPK1
      H(2,3)=(-OPTK*RATIOP+GKP)/ZPK1*P
      IF(IBODE .EQ. 1) GO TO 705
        RATIO = OPTK
      GO TO 900
  705   RATIO = -RATIO/(1.+RATIO)
      GO TO 900
  710 CONTINUE
C
C   ***              POINT KINETICS              ***
C   ***    ICASE = 2,  NON-UNIFORM RADIAL        ***
C   ***    ICASE = 11, CHECKER BOARD PROBLEM ***
C
      JRMAX=JMX(IMAX)
      NCHQ=JJD(IMAX,JRMAX)
      RATIOP=CMPLX(0.,0.)
      DO 311 I=1,IMAX
      JR=JMX(I)
      DO 311 J=1,JR
      M=JJD(I,J)
      MC=IDCHTY(I,J)
      WZP=AAA(M)*VOL/AVEQ
      RATIOP=RATIOP+WZP*XKPRA(MC)/(1.-WZP*XKRA(MC,MC))
     @         /FLOAT(NCHQ)
  311 CONTINUE
      JRMX=JMX(IMAX)
      NMXM=JJD(IMAX,JRMX)
      RATIO = CMPLX(0.,0.)
      DO 711 I=1,IMAX
      JR-JMX(I)
      DO 711 J=1,JR
      M=JJD(I,J)
      MY=ITY(M)
      WZP=AAA(M)/AVEQ
  711 RATIO = RATIO - WZP*F1(MY)/FLOAT(NMXM)
      IF(IBODE .EQ. 1) GO TO 712
      GO TO 900
  712 RATIO = -RATIO/(1.+RATIO)
      GO TO 900
  720 CONTINUE
C
C   ***                COUPLED KINETICS           ***
C   ***     ICASE = 4, RADIAL COUPLING(2-D)      ***
C   ***   ICASE = 10, CHECKER BOARD PROBLEM     ***
C
      IF(ICASE .EQ. 4)CALL OPEN4(S,RATIO,NCH1,ICOUNT,KMAX4)
      IF(ICASE .EQ. 10)CALL OPEN1(S,RATIO,NCH1,ICOUNT,KMAX4)
      IF(IBODE .NE. 0)GO TO 721
      GO TO 900
  721 RATIO=-RATIO/(1.+RATIO)
C
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```
      GO TO 900
  730 CONTINUE
C
C  *****    AXIALLY COUPLED KINETICS            *****
C  *****  ICASE = 5  : SPECIFIC CHANNEL         *****
C  *****  ICASE = 6  : AVERAGE CHANNEL          *****
C  *****  ICASE = 13 : HOT CHANNEL, TWO GROUP   *****
C
      CALL OPEN1(S,RATIO,NCH1,ICOUNT,KMAX4)
      IF(IBODE .NE. 0)GO TO 641
      GO TO 900
  641 RATIO=-RATIO/(1.+RATIO)
      GO TO 900
  740 CONTINUE
C
C  *****             POINT KINETICS           *****
C  *****  ICASE = 3  :  NON-UNIFORM AXIAL *****
C  *****  ICASE = 7  :  SPECIFIC CHANNEL  *****
C
      JRMAX=JMX(IMAX)
      NCHQ=JJD(IMAX,JRMAX)
      RATIOP=CMPLX(0.,0.)
      M=JJD(ISPEC,JSPEC)
      IY=ITY(M)
      DO 345 K=1,KMAX
      WZP=AAA(K)*VOL/AVEQ
      RATIOP=RATIOP+WZP*XKP(IY,K)/(1.-WZP*XK(IY,K,IY,K))/
     @         FLOAT(KMAX)
  345 CONTINUE
      RATIO = CMPLX(0.,0.)
      IF(ICASE.EQ.3) NCC=NCH1
      IF(ICASE.EQ.7) NCC=JJD(ISPEC,JSPEC)
      NCCY=ITY(NCC)
      DO 741 K=1,KMAX
      F22=FALF(NCCY,K)
      WZP=AAA(K)/AVEQ
      RATIO = RATIO - WZP*F22/FLOAT(KMAX)
  741 CONTINUE
      IF(IBODE .NE. 0)GO TO 743
      GO TO 900
  743 RATIO=-RATIO/(1.+RATIO)
      GO TO 900
C
  750 CONTINUE
C
C   ***        GENERAL KINETICS        ***
C   ***    ICASE = 8,  3-D COUPLING    ***
C
C
      CALL OPEN8(S,RATIO,NCH1,ICOUNT,KMAX4)
      IF(IBODE .NE. 0)GO TO 751
      GO TO 900
  751 RATIO=-RATIO/(1.+RATIO)
  900 CONTINUE
      RETURN
      END
C
C
C
C************************************************************
```

```
C     VARIOUS FUNCTION
C******************************************************
C
C...............................................................
      REAL FUNCTION HL(P,T)
C...............................................................
C     *          HL ;  LIQUID ENTHALPY  0-P-2120 PSIA
C     REAL HL
      HL = 0.001618*P - 47.62 + (0.965566 - 4.982E-6*P)*T+
     1  (8.2445*P - 8843.4)/(802.-T) + (6.6612*P-20392.)/(T - 750.)
      RETURN
      END
C
C..............................................................
      FUNCTION DENS(P,T,HPT)
C..............................................................
C     *          DENS ;   LIQUID DENSITY    0-P-2120 PSIA
      HPT = HL(P,T)
      IF(HPT .GE. 280.)    GO TO 100
      DENS = 2.14E-4*P +62.4 +(1.438E-9*P- 8.73E-5)*HPT**2
     1 + (2.32E-10 - 6.2E-15*P)*HPT**4
      RETURN
  100 DENS = 5.761E-4*P+92.924 + (1.6386*P+39440.2)/(HPT-(0.035704*P
     1 + 1377.35))
      RETURN
      END
C
C...............................................................
      FUNCTION  VF(P)
C..............................................................
C
      VF = 1.7087E-02 + 0.6925E-05*P - 0.4254E-08*P**2 + 0.2180E-11*
     @     P**3- 0.0357E-14*P**4
      RETURN
      END
C..............................................................
      FUNCTION DRFDP(P)
C..............................................................
      DVF=.6925E-05-.8508E-08*P+.654E-11*P**2-.1428E-14*P**3
      DRFDP=-DVF/VF(P)**2
      RETURN
      END
C
C..............................................................
      FUNCTION  VFG(P)
C..............................................................
C
      VFG = 2.6454 - 5.9326E-03*P + 6.5891E-06*P**2 - 3.9249E-09*P**3
     C      + 1.1897E-12*P**4 - 0.1441E-15*P**5
      RETURN
      END
C
C...............................................................
      FUNCTION  HF(P)
C...............................................................
C
      HF = 323.9128 + 0.2964306*P - 0.944149E-04*P**2
     C     + 0.165674E-07*P**3
      RETURN
      END
```

```
C
C.................................................................
      FUNCTION HFG(P)
C.................................................................
C
      HFG = 883.6608 - 0.2911105*P + 0.743325E-04*P**2
     C       - 0.165592E-07*P**3
      RETURN
      END
C
C................................................................
      REAL FUNCTION MUTL(T)
C................................................................
C     *          VISCOSITY OF SATURATED LIQUID WATER IN RANGE
C                                32 TO 572 DEG. F(LBM/HR-FT)
C     *                    REF - ASME STEAM TABLES, PAGE 74
      MUTL  = 0.0584*10.0**(446.04/(207.6+T))
      RETURN
      END
C
C.................................................................
      FUNCTION COND(T)
C................................................................
C     *        THERMAL CONDUCTIVITY OF SATURATED WATER IN RANGE
C                                32 TO  622 DEG. F(BTU/HR-FT-DEG.F)
      DATA A0, A1, A2, A3, A4 /-0.53299, 1.6406,  -1.0404, 0.30378,
     1        -0.042433/
      TT = (T + 459.67)/491.67
      COND = A0 + A1*TT + A2*TT*TT + A3*TT**3 + A4*TT**4
      RETURN
      END
C
C
C.................................................................
      REAL FUNCTION MARNEL(P,G)
C.................................................................
C     *    CALCULATION OF PI(P,G) IN THE MARTINELLI-NELSON CORRELATION
C                FOR THE TWO-PHASE MULTIPLIER
      GHR = G*3600.
      G6 = GHR/1.E+06
      IF(G6 .GT. 0.7) GO TO 10
      MARNEL = 1.36 + 0.0005*P + 0.1*G6 - 0.000714*P*G6
      RETURN
C
   10 MARNEL = 1.26 - 0.0004*P + 0.119/G6 + 0.00028*P/G6
      RETURN
      END
C
C
C
C
      FUNCTION CONPI(X)
      IF(X .GE. 2.) GO TO 1
      CONPI = 1.
      GO TO 2
    1 CONPI = (X/0.61)**0.47
    2 RETURN
      END
C
C
```

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```
C
C
      FUNCTION CCON(X)
      IF(X .GT. 145.) GO TO 1
      CCON = 61. - 6.389E-05*(X-1.7E+05)
      GO TO 2
    1 CCON = 0.23E+10*X**(-1.418)
    2 RETURN
      END
C
C.................................................................
        FUNCTION ANGL(COMP)
C.................................................................
        COMPLEX COMP
      FIMAG=AIMAG(COMP)
      DREAL=REAL(COMP)
      SREAL = DREAL**2
      SQMOD=FIMAG**2+DREAL**2
      IF(SREAL.LE.1.0E-30) GO TO 931
      ANGL=57.296*ATAN2(FIMAG,DREAL)
      RETURN
  931 ANGL=90.0
      IF(FIMAG.LE.0.0)ANGL=-90.0
      IF(SQMOD.LE.1.0E-30)ANGL=0.0
      RETURN
      END
C
C...............................................................
      COMPLEX FUNCTION CCOTH(Z)
C..............................................................
C     *        CALCULATE COTH(Z)     ,WHERE Z IS A COMPLEX VARIABLE
C
      COMPLEX Z
      IF(CABS(Z) .GE. 99.) GO TO 1
      CCOTH = (CEXP(Z)+CEXP(-Z)) / (CEXP(Z)-CEXP(-Z))
      GO TO 2
C
    1 CCOTH = CMPLX(1.,0.)
    2 RETURN
      END
C
C
C..............................................................
      COMPLEX FUNCTION EPOW(X,Z)
C.............................................................
C     * CALCULATE X**Z    ( Z ; COMPLEX VARIABLE )
C
      COMPLEX Z,Z1
      IF(X .EQ. 1.) GO TO 10
      Z1 = Z*ALOG(X)
      EPOW = CEXP(Z1)
      GO TO 20
   10 EPOW = CMPLX(1.,0.)
   20 RETURN
      END
C
C
C.................................................................
      COMPLEX FUNCTION BSI0(Z)
C.................................................................
```

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```
C     *  MODIFIED BESSEL FUNCTION OF THE FIRST KIND OF ORDER ZERO
C               I0(Z*SQRT(I)) = BER(Z) + I*BEI(Z)
C
      Z1 = BER(Z)
      Z2 = BEI(Z)
      BSI0 = CMPLX(Z1,Z2)
      RETURN
      END
C
C..............................................................
      COMPLEX FUNCTION BSI1(Z)
C..............................................................
C     *  MODIFIED BESSEL FUNCTION OF THE FIRST KIND OF ORDER ONE
C               I1(Z*SQRT(I)) = BEI1(Z) - I*BER1(Z)
C                   WHERE  BEI1(Z) = (SQRT(2)/2) * (BER'(Z)+BEI'(Z))
C                          BER1(Z) = (SQRT(2)/2) * (BER'(Z)-BEI'(Z))
C
      BEI1 = 0.707107 * (BERS(Z) + BEIS(Z))
      BER1 = 0.707107 * (BERS(Z) - BEIS(Z))
C
      BSI1 = CMPLX(BEI1, -BER1)
      RETURN
      END
C
C..............................................................
      COMPLEX FUNCTION BSK0(Z)
C..............................................................
C     *  MODIFIED BESSEL FUNCTION OF THE SECOND KIND OF ORDER ZERO
C               K0(Z*SQRT(I)) = RKER(Z) + I*RKEI(Z)
C
      Z1 = RKER(Z)
      Z2 = RKEI(Z)
      BSK0 = CMPLX(Z1,Z2)
      RETURN
      END
C
C..............................................................
      COMPLEX FUNCTION BSK1(Z)
C..............................................................
C     *  MODIFIED BESSEL FUNCTION OF THE SECOND KIND OF ORDER ONE
C               K1(Z*SQRT(I)) = -RKEI1(Z) + I*RKER1(Z)
C                   WHERE  RKEI1(Z) = (SQRT(2)/2) * (RKER'(Z)+RKEI'(Z))
C                          RKER1(Z) = (SQRT(2)/2) * (RKER'(Z)-RKEI'(Z))
C
      REAL RKEI1, RKER1
      RKEI1 = 0.707107 * (RKERS(Z) + RKEIS(Z))
      RKER1 = 0.707107 * (RKERS(Z) - RKEIS(Z))
C
      BSK1 = CMPLX(-RKEI1, RKER1)
C
      RETURN
      END
C
C..............................................................
      FUNCTION BER(Z)
C..............................................................
C          ***   BER FUNCTION   ***
C
      DIMENSION P(7)
      DATA P/ -64.0      , 113.777778, -32.363457,   2.641914,
     1          -0.083496,   0.001226,  -0.000009/
      DATA PI/3.141593/
C
      IF(Z .GT. 10) GO TO 10
      Y = Z/8.
      BER = 1.
      DO 1 I=1,7
      I4 = 4 * I
      BER = BER + P(I)*Y**I4
    1 CONTINUE
      RETURN
C
C* ASYMPTOTIC SOLUTION FOR  Z>10
   10 Z1 = (PI/180.) * (40.514*Z + 67.5)
      Z2 = (PI/180.) * (40.514*Z + 22.5)
      BER = (0.3989*EXP(Z/1.414214)/SQRT(Z)) * (SIN(Z1)+SIN(Z2)/(8.*Z))
      RETURN
      END
C
C..................................................................
      FUNCTION BEI(Z)
C..................................................................
C          ***   BEI FUNCTION   ***
C
      DIMENSION P(7)
      DATA P/ 16.0      ,-113.777778,  72.817777, -10.567658,
     1           0.521856,  -0.011037,  +0.000113/
      DATA PI/3.141593/
C
      IF(Z .GT. 10) GO TO 10
      Y = Z/8.
      BEI = 0.
      DO 1 I=1,7
      II = 2 * (2*I - 1)
      BEI = BEI + P(I)*Y**II
    1 CONTINUE
      RETURN
C
C* ASYMPTOTIC SOLUTION FOR  Z>10
   10 Z1 = (PI/180.) * (40.514*Z - 22.5)
      Z2 = (PI/180.) * (40.514*Z - 67.5)
      BEI = (0.3989*EXP(Z/1.414214)/SQRT(Z)) * (SIN(Z1)+SIN(Z2)/(8.*Z))
      RETURN
      END
C
C..................................................................
      FUNCTION BEIS(Z)
C..................................................................
C          ***   BEI'   FUNCTION   ***
C
      DIMENSION P(6)
      DATA P/ -10.666667,  11.377778,  -2.311675,   0.146772,
     1          -0.003794,   0.000046/
      DATA PI/3.141593/
C
      IF(Z .GT. 10) GO TO 10
      Y = Z/8.
      BEIS = 0.5
      DO 1 I=1,6
      I4 = 4 * I
      BEIS = BEIS + P(I)*Y**I4
    1 CONTINUE
      BEIS = Z*BEIS
      RETURN
C
C* ASYMPTOTIC SOLUTION FOR  Z>10
   10 Z1 = (PI/180.) * (40.514*Z + 22.5)
      Z2 = (PI/180.) * (40.514*Z - 22.5)
      BEIS = (0.3989*EXP(Z/1.414214)/SQRT(Z))
     1                   * (SIN(Z1) - SIN(Z2)*(3./(8.*Z)))
      RETURN
      END
C
C.......................................................................
      FUNCTION BERS(Z)
C.......................................................................
C         ***   BER'  FUNCTION   ***
C
      DIMENSION P(7)
      DATA P/ -4.0      ,  14.222222,  -6.068148,   0.660478,
     1        -0.026093,   0.000460,  -0.000004/
      DATA PI/3.141593/
C
      IF(Z .GT. 10) GO TO 10
      Y = Z/8.
      BERS = 0.
      DO 1 I=1,7
      I1 = 2 * (2*I - 1)
      BERS = BERS + P(I)*Y**I1
    1 CONTINUE
      BERS = Z*BERS
      RETURN
C
C* ASYMPTOTIC SOLUTION FOR  Z>10
   10 Z1 = (PI/180.) * (40.514*Z + 112.5)
      Z2 = (PI/180.) * (40.514*Z + 67.5)
      BERS = (0.3989*EXP(Z/1.414214)/SQRT(Z)) * (SIN(Z1)-SIN(Z2)
     1          *(3./(8.*Z)))
      RETURN
      END
C
C.......................................................................
      REAL FUNCTION RKER(Z)
C.......................................................................
C         ***   KER  FUNCTION   ***
C
      DIMENSION P(7)
      DATA P/-59.058197, 171.362721, -60.609775,   5.655391,
     1        -0.196363,   0.003097,  -0.000025/
      DATA PI/3.141593/
C
      IF(Z .GT. 10) GO TO 10
      IF(Z .LT. 1) GO TO 20
C
      X1 = Z/2.
      X = -ALOG(X1)*BER(Z) + (PI/4.)*BEI(Z)
      Y = Z/8.
      RKER = -0.577216
      DO 1 I=1,7
      I4 = 4 * I
      RKER = RKER + P(I)*Y**I4
    1 CONTINUE
      RKER = X + RKER
      RETURN
C
C    * ASYMPTOTIC SOLUTION FOR  Z>10
   10 Z1 = (PI/180.) * (40.514*Z + 112.5)
      Z2 = (PI/180.) * (40.514*Z - 22.5)
      RKER = (1.2533*EXP(-Z/1.414214)/SQRT(Z)) * (SIN(Z1)+SIN(Z2)
     1          /(8.*Z))
      RETURN
C
   20 A0 = 0.115932 - ALOG(Z)
      X = Z/2.
      RKER = A0 + (PI/4.)*X**2 - ((A0+3./2.)/4.)*X**4
     1          - (PI/144.)*X**6 + ((A0+25./12.)/576.)*X**8
      RETURN
      END
C
C.................................................................
      REAL FUNCTION RKEI(Z)
C.................................................................
C         ***   KEI   FUNCTION   ***
C
      DIMENSION P(7)
      DATA P/  6.764549,-142.918277, 124.235697, -21.300609,
     1          1.175091,  -0.026959,   0.000295/
      DATA PI/3.141593/
C
      IF(Z .GT. 10) GO TO 10
      IF(Z .LT. 1) GO TO 20
C
      X1 = Z/2.
      X = -ALOG(X1)*BEI(Z) - (PI/4.)*BER(Z)
      Y = Z/8.
      RKEI = 0.
      DO 1 I=1,7
      II = 2 * (2*I - 1)
      RKEI = RKEI + P(I)*Y**II
    1 CONTINUE
      RKEI = X + RKEI
      RETURN
C
C    * ASYMPTOTIC SOLUTION FOR  Z>10
   10 Z1 = (PI/180.) * (40.514*Z + 22.5)
      Z2 = (PI/180.) * (40.514*Z + 67.5)
      RKEI = (1.2533*EXP(-Z/1.414214)/SQRT(Z)) * (-SIN(Z1)+SIN(Z2)
     1          /(8.*Z))
      RETURN
C    * FOR  Z<1
   20 A0 = 0.115932 - ALOG(Z)
      X = Z/2.
      RKEI = -PI/4. + (A0+1.)*X**2 - (PI/16.)*X**4
     1          - ((A0+11./6.)/36.)*X**6 + (PI/2304.)*X**8
      RETURN
      END
C
C.................................................................
      REAL FUNCTION RKEIS(Z)
C.................................................................
```

```
C          ***   KEI'  FUNCTION   ***
C
      DIMENSION P(6)
      DATA P/-13.398589,  19.411828,  -4.659508,   0.330494,
     1        -0.009267,   0.000120/
      DATA PI/3.141593/
C
      IF(Z .GT. 10) GO TO 10
      IF(Z .LT. 1) GO TO 20
C
      X1 = Z/2.
      X = -ALOG(X1)*BEIS(Z) -BEI(Z)/Z - (PI/4.)*BERS(Z)
      Y = Z/8.
      RKEIS = 0.211392
      DO 1 I=1,6
      I4 = 4 * I
      RKEIS = RKEIS + P(I)*Y**I4
    1 CONTINUE
      RKEIS = X + Z*RKEIS
      RETURN
C
C     * ASYMPTOTIC SOLUTION FOR  Z>10
   10 Z1 = (PI/180.) * (40.514*Z - 22.5)
      Z2 = (PI/180.) * (40.514*Z + 22.5)
      RKEIS = (1.2533*EXP(-Z/1.414214)/SQRT(Z)) * (SIN(Z1)+SIN(Z2)
     1            *(3./(8.*Z)))
      RETURN
C     * FOR  Z<1
   20 A0 = 0.115932 - ALOG(Z)
      X = Z/2.
      RKEIS = (A0+0.5)*X + PI*X**3/8. - (A0+5./3.)*X**5/12.
     1             - (PI*X**7)/576.
      RETURN
      END
C
C.................................................................
      REAL FUNCTION RKERS(Z)
C.................................................................
C          ***   KER'  FUNCTION   ***
C
      DIMENSION P(7)
      DATA P/ -3.691137,  21.420340, -11.364333,   1.413848,
     1        -0.061364,   0.001161,  -0.000011/
      DATA PI/3.141593/
C
      IF(Z .GT. 10) GO TO 10
      IF(Z .LT. 1) GO TO 20
C
      X1 = Z/2.
      X = -ALOG(X1)*BERS(Z) -BER(Z)/Z + (PI/4.)*BEIS(Z)
      Y = Z/8.
      RKERS = 0.
      DO 1 I=1,7
      I1 = 2 * (2*I - 1)
      RKERS = RKERS + P(I)*Y**I1
    1 CONTINUE
      RKERS = X + Z*RKERS
      RETURN
C
C     * ASYMPTOTIC SOLUTION FOR  Z>10
```

```
   10 Z1 = (PI/180.) * (40.514*Z + 67.5)
      Z2 = (PI/180.) * (40.514*Z + 112.5)
      RKERS = -(1.2533*EXP(-Z/1.414214)/SQRT(Z)) * (SIN(Z1)+SIN(Z2)
     1             *(3./(8.*Z)))
      RETURN
C     * FOR  Z<1
   20 A0 = 0.115932 - ALOG(Z)
      X = Z/2.
      RKERS = -(0.5/X) + PI*X/4. - (A0+5./4.)*0.5*X**3
     1            - (PI*X**5)/48. + (A0+47./24.)*X**7/144.
      RETURN
      END
C
C
C PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C  PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
C CALCULATE STATE PARAMETERS FROM KAPL FITS
C ....................................................................
      FUNCTION DVG1(P)
C ....................................................................
      DVG1=-5.9319E-3+1.3177E-5*P-1.1768E-8*P**2
     1       +4.772E-12*P**3-7.205E-16*P**4
      RETURN
      END
C
C ....................................................................
      FUNCTION DHF1(P)
C ..................................................................
      DHF1=0.2964306-1.888298E-4*P-4.97022E-8*P**2
      RETURN
      END
C
C ....................................................................
      FUNCTION DHG1(P)
C ....................................................................
      DHG1=0.00532-4.01648E-5*P+2.46E-11*P**2
      RETURN
      END
C
C ....................................................................
      FUNCTION DCZER1(RHOG,DENSF,DRHOG,ION)
C ....................................................................
      IF(ION .EQ. 0 ) GOTO 10
      DCZER1=-0.1/(DENSF*RHOG)**.5*(DRHOG-RHOG/DENSF*DRFDP(P))
      GOTO 100
 10   DCZER1=0.0
 100  RETURN
      END
C
C ....................................................................
      FUNCTION DVGJ1(RHOG,DENSF,DRHOG,TAVE,P,ION)
C ....................................................................
      IF(ION .EQ. 0)GOTO 10
      SIGMA=-9.14285E-6*TAVE+6.2E-3
      DSDP=-9.14285E-6*.5*DTSDP(P)
      DVGJ1=.725*1/((((DENSF-RHOG)*SIGMA*32.2*32.2)/DENSF**2)**.75)
     1      *(-SIGMA*32.2*32.2/DENSF**2)*(DRHOG-(DENSF-RHOG)*
     @         DSDP/SIGMA-DRFDP(P)*(2.*RHOG/DENSF-1.))
      GOTO 100
10    DVGJ1=0.0
```

```
  100 RETURN
      END
C
C.....................................................................
      FUNCTION DRGDP(P)
C.....................................................................
C
      DVGDP=-5.9319E-3+13.1774E-6*P-11.7681E-9*P**2
     @ +4.7572E-12*P**3-.7205E-15*P**4
      DRGDP=-DVGDP/(VFG(P)+VF(P))**2
      RETURN
      END
C
C.....................................................................
      FUNCTION DVFGDP(P)
C.....................................................................
C
      DVFGDP=-5.9319E-3+13.1774E-6*P-11.7681E-9*P**2
     @ +4.7572E-12*P**3-.7205E-15*P**4
      RETURN
      END
C
C.....................................................................
      FUNCTION DISDP(P)
C.....................................................................
C
      DATA B2,B3,B4,B5/65.14, 24.859, -4.3391, 1.6889/
      X=ALOG10(P)
      DXDP=1./(P*ALOG10(P))
      DISDP=DXDP*(B2+2.*B3*X+3.*B4*X**2+4.*B5*X**3)
      RETURN
      END
C
C.....................................................................
      FUNCTION DHFGDP(P)
C.....................................................................
C
      DHFGDP=DHG1(P)-DHF1(P)
      RETURN
      END
C
C
C
C
      FUNCTION SGMA(P,TF)
C     ... SURFACE TENSION OF WATER(LBF/FT) AS FUNCTION OF PRESSURE
C         & SATURATED WATER TEMPERATURE
      DIMENSION A(5)
      DATA A/1.1609368E-01, 1.1214046E-03, -5.7528051E-06,
     1        1.2862746E-08, -1.1497192E-11/
C
      SGMA = -1.0
      TR = (TF-32.0)*0.555555
      IF(TR .LT. 0. .OR. TR .GT. 374.15) GO TO 20
      TKMT = 374.15 - TR
      TKMTS = TKMT**2
      SGMA = (A(1)*TKMTS) / (1.0+0.83*TKMT)
      DO 10 N=2,5
      SGMA = SGMA + A(N)*TKMTS
      TKMTS = TKMTS*TKMT
```

```
   10 CONTINUE
      SGMA = SGMA*0.68524E-04
   20 CONTINUE
C
      RETURN
      END
C
C
C
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      COMPLEX FUNCTION GIFN1(A,B,Y)
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C     * CALCULATION OF INCOMPLETE GAMMA FUNCTION
C
      COMPLEX A, B, Y
      COMPLEX*16 Z1, Z(100), X1, Z2, Z3, T1
      DOUBLE PRECISION F1,F2,DREAL,DIMAG,DIFF1,DIFF2
C
      Z2 = 1. + Y
      Z1 = CEXP(-B)/B
      X1 = (A-1.)/B
      Z(1) = (1.-CEXP(-Y)) + X1*(1.-CEXP(-Y)*Z2)
      N = 1
  300 N = N+1
      IF(N .GT. 100) GO TO 100
      N1 = N-1
      X1 = X1*(A-FLOAT(N))/B
      F1 = FLOAT(N) + 1
      F2 = DGAMMA(F1)
      Z3 = FLOAT(N)*CLOG(Y)
      Z2 = Z2 + CDEXP(Z3)/F2
      T1 = 1.-CEXP(-Y)*Z2
      IF(CDABS(T1) .LE. 1.0E-06) T1 = CMPLX(0.,0.)
      Z(N) = Z(N1) + X1*T1
C
       IF(DREAL(Z(N)) .LE. 1.0E-06) GO TO 402
      DIFF1 = (DREAL(Z(N))-DREAL(Z(N1))) / DREAL(Z(N))
      DIFF1 = DABS(DIFF1)
      GO TO 403
  402 DIFF1 = DREAL(Z(N)) - DREAL(Z(N1))
      DIFF1 = DABS(DIFF1)
  403  IF(DIMAG(Z(N)) .LE. 1.0E-06) GO TO 400
      DIFF2 = (DIMAG(Z(N))-DIMAG(Z(N1))) / DIMAG(Z(N))
      DIFF2 = DABS(DIFF2)
       GO TO 401
  400 DIFF2 = DIMAG(Z(N)) - DIMAG(Z(N1))
      DIFF2 = DABS(DIFF2)
  401 IF(DIFF1 .LE. 1.0E-04 .AND. DIFF2 .LE. 1.0E-04) GO TO 200
      GO TO 300
C
  200 GIFN1 = Z1*Z(N)
      GO TO 201
  100 WRITE(6,10)
   10 FORMAT(/5X,'***  GAMMA FUNCTION DIVERGE  ***')
      STOP
  201 RETURN
      END
C
C
C
```

```
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      COMPLEX FUNCTION GIFN2(A,CB,CZ)
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C     * CALCULATION OF INTEGRAL OF THE PRODUCT OF POWERS &
C                   EXPONENTIAL FUCTION
C
      COMPLEX A
      COMPLEX*16 C(100), F3, P1
      DOUBLE PRECISION B,Z,Q1,F1,F2,DREAL,DIMAG,DIFF1,DIFF2
C
      B = DBLE(CB)
      Z = DBLE(CZ)
      P1 = CDEXP((A-1.)*DLOG(B))
      Q1 = B*Z
      IF(REAL(1.-A).EQ.0. .AND. AIMAG(1.-A).EQ.0.) GO TO 305
      IF(REAL(2.-A).EQ.0. .AND. AIMAG(2.-A).EQ.0.) GO TO 306
      C(1) = (CDEXP((1.-A)*DLOG(Q1))-CDEXP((1.-A)*DLOG(B)))/(1.-A)
     1     + (CDEXP((2.-A)*DLOG(Q1))-CDEXP((2.-A)*DLOG(B)))/(2.-A)
      GO TO 307
  305 C(1) = DLOG(Q1/B) + (CDEXP((2.-A)*DLOG(Q1))-
     1                     CDEXP((2.-A)*DLOG(B)))/(2.-A)
      GO TO 307
  306 C(1) = (CDEXP((1.-A)*DLOG(Q1))-CDEXP((1.-A)*DLOG(B)))/(1.-A)
     1           + DLOG(Q1/B)
  307 N = 1
  300 N = N+1
      IF(N .GT. 100) GO TO 100
      N1 = N-1
      F1 = FLOAT(N) + 1
      F2 = DGAMMA(F1)
      F3 = F1 - A
      IF(DREAL(F3).EQ.0. .AND. DIMAG(F3).EQ.0.) GO TO 301
      C(N) = C(N1) + (CDEXP(F3*DLOG(Q1))-CDEXP(F3*DLOG(B)))
     1               / (F3*F2)
      GO TO 302
  301 C(N) = C(N1) + DLOG(Q1/B)
C
  302  IF(DREAL(C(N)) .LE. 1.0E-06) GO TO 402
      DIFF1 = (DREAL(C(N))-DREAL(C(N1))) / DREAL(C(N))
      DIFF1 = DABS(DIFF1)
      GO TO 403
  402 DIFF1 = DREAL(C(N)) - DREAL(C(N1))
      DIFF1 = DABS(DIFF1)
  403  IF(DIMAG(C(N)) .LE. 1.0E-06) GO TO 400
      DIFF2 = (DIMAG(C(N))-DIMAG(C(N1))) / DIMAG(C(N))
      DIFF2 = DABS(DIFF2)
       GO TO 401
  400 DIFF2 = DIMAG(C(N)) - DIMAG(C(N1))
      DIFF2 = DABS(DIFF2)
  401 IF(DIFF1 .LE. 1.0E-04 .AND. DIFF2 .LE. 1.0E-04) GO TO 200
      GO TO 300
C
  200 GIFN2 = P1*C(N)
      GO TO 201
  100 WRITE(6,10)
   10 FORMAT(/5X,'***  EXP & POW INTEGRAL IS DIVERGE  ***')
      STOP
  201 RETURN
      END
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
```

```
C     $                                                           $
C     $           SUBROUTINES FOR NUCLEAR COUPLING                $
C     $                                                           $
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
C
C*****************************************************************
      SUBROUTINE NUCLER
C*****************************************************************
C
C  ***  THIS ROUTINE READS 3-DIMENSIONAL NUCLEAR INPUT DATA, POWER,
C  ***  EXPOSURE, VOID, ALBEDO, AND TWO GROUP FLUXES AT STEADY
C  ***  STATE CASE FROM "SIMULATE" OUTPUT FOR 1/8 CORE
C
C
      DIMENSION JJMX(20),TITLE(20),TITL1(20),TITL2(20),TITL3(20),
     1          TITL4(20),TITL5(20),TITL6(20),TITL7(20),TITL8(20)
      DIMENSION NFUEL(15,15),NCONTL(15,15)
      COMMON/SIM1/IMAX,JMAX,KMAX,ICASE,ISPEC,JSPEC,INUCLR,XKEFF
      COMMON/SIM2/JMX(20),NFT(15,15,30),AL(15,15),TAL(15,15),
     1          BAL(15,15),ASRC(15,15),SRC(15,15,30),AEXP(15,15),
     2          REXP(15,15,30),AXSRC(30),XXSRC(30)
      COMMON/SIM3/JJD(15,15),DZ1(200),DZ2(200),NF(200,30),NB(200),
     1          SC(200,30,6),XEXP(200,30),SIG1(200,30,11),
     2          CSIG1(200,30,11)
      COMMON/SIM6/RHOX(15,15,30),RHOZ(15,15,30),RX(15,15,30),
     1          RZ(15,15,30),TEEO(15,15,30),PLAMDA(6), FPDF(15),
     2          FPLAM(15)
C
C
C
C
  500 FORMAT(20A4)
  502 FORMAT(8I5)
  504 FORMAT(8F10.4)
  505 FORMAT(6E10.4)
  506 FORMAT(15I5)
  512 FORMAT(I2,1X,11F7.4)
  513 FORMAT(10F8.4)
  514 FORMAT(11F7.4)
C
C
      IN=7
      READ(IN,500) TITLE
      READ(IN,504) XKEFF
      READ(IN,502) IMAX,JMAX,KMAX,INUCLR,NFTYPE,ICHEK
      READ(IN,504) (PLAMDA(JJ),JJ=1,6)
      READ(IN,505) (FPDF(JJ),JJ=1,11)
      READ(IN,505) (FPLAM(JJ),JJ=1,11)
      READ(IN,506) (JMX(I),I=1,IMAX)
      READ(IN,506) (JJMX(I),I=1,IMAX)
      READ(IN,500) TITL1
C
      ID=0
      DO 15 I=1,IMAX
      JR=JMX(I)
      DO 14 J=1,JR
      JJD(I,J)=ID+J
   14 CONTINUE
      ID=JJD(I,JR)
   15 CONTINUE
C
      DO 20 I=1,IMAX
      JJR=JJMX(I)
      READ(IN,506) (NFUEL(I,J),J=1,JJR)
   20 CONTINUE
C
      READ(IN,500)
      DO 22 I=1,IMAX
      JJR=JJMX(I)
      READ(IN,506) (NCONTL(I,J),J=1,JJR)
   22 CONTINUE
C
      DO 28 I=1,IMAX
      JJR=JJMX(I)
      DO 28 J=1,JJR
      KCC=KMAX-NCONTL(I,J)
      KL=KCC+1
      IF(KCC.EQ.KMAX) GO TO 24
      DO 23 K=KL,KMAX
   23 NFT(I,J,K)=NFUEL(I,J)
C
      IF(KCC.EQ.0) GO TO 28
   24 CONTINUE
C
      DO 25 K=1,KCC
   25 NFT(I,J,K)=NFUEL(I,J)+NFTYPE
   28 CONTINUE
C
      READ(IN,500) TITL2
C
      DO 30 I=1,IMAX
      JJR=JJMX(I)
      READ(IN,514) (AL(I,J),J=1,JJR)
   30 CONTINUE
C
      READ(IN,500) TITL3
C
      DO 35 I=1,IMAX
      JJR=JJMX(I)
      READ(IN,514) (TAL(I,J),J=1,JJR)
   35 CONTINUE
C
      READ(IN,500) TITL4
C
      DO 40 I=1,IMAX
      JJR=JJMX(I)
      READ(IN,514) (BAL(I,J),J=1,JJR)
   40 CONTINUE
C
      READ(IN,500) TITL5
C
      DO 45 I=1,IMAX
      JJR=JJMX(I)
      READ(IN,512) IL,(ASRC(I,J),J=1,JJR)
   45 CONTINUE
C
      READ(IN,500) TITL6
C
      DO 50 I=1,IMAX
      READ(IN,500)
      JJR=JJMX(I)
      DO 50 KK=1,KMAX
      K=KMAX-KK+1
      READ(IN,512) IL,(SRC(I,J,K),J=1,JJR)
   50 CONTINUE
C
C
      READ(IN,500) TITL7
C
      DO 65 I=1,IMAX
      JJR=JJMX(I)
      READ(IN,512) IL,(AEXP(I,J),J=1,JJR)
   65 CONTINUE
C
      READ(IN,500) TITL8
C
      DO 70 I=1,IMAX
      READ(IN,500)
      JJR=JJMX(I)
      DO 70 KK=1,KMAX
      K=KMAX-KK+1
      READ(IN,512) IL,(REXP(I,J,K),J=1,JJR)
   70 CONTINUE
C
C
C
   76 CONTINUE
C
      READ(IN,513) (AXSRC(K),K=1,KMAX)
      IF(ICHEK.EQ.1) GO TO 110
C
      DO 100 I=1,IMAX
      INV=IMAX-I+1
      JJR=JJMX(I)
      JR=JMX(I)
      DO 100 J=1,JJR
      JNV=IMAX-J+1
C
      DO 80 K=1,KMAX
      NFT(JNV,INV,K)=NFT(I,J,K)
      SRC(JNV,INV,K)=SRC(I,J,K)
      REXP(JNV,INV,K)=REXP(I,J,K)
   80 CONTINUE
C
      AL(JNV,INV)=AL(I,J)
      TAL(JNV,INV)=TAL(I,J)
      BAL(JNV,INV)=BAL(I,J)
      ASRC(JNV,INV)=ASRC(I,J)
      AEXP(JNV,INV)=AEXP(I,J)
  100 CONTINUE
C
  110 CONTINUE
      RETURN
      END
C
C******************************************************************
      SUBROUTINE XSMODL
C******************************************************************
C
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```
C     * THIS ROUTINE CALCULATES FITTING COEFFICIENTS OF DATA AT
C       CERTAIN EXPOSURE AND VOID FRACTION
C
      DIMENSION FLUX(2,3,3),SIGA(2,3,3),SIGF(2,3,3),TITLE(80),
     1          VN2(2,3,3),BT(3,3,6),XSC(3,3,11),REFE(3),REFU(3),
     2          DIFF(2,3,3),SIG12(2,3,3)
C
C
      COMMON/SIM1/IMAX,JMAX,KMAX,ICASE,ISPEC,JSPEC,INUCLR,XKEFF
      COMMON/COEF1/C1(10,2,11),C2(10,2,11),C3(10,2,11),C4(10,2,11),
     1             C5(10,2,11),C6(10,2,11),C7(10,2,11),C8(10,2,11),
     2             C9(10,2,11),C10(10,2,11),C11(10,2,11)
      COMMON/COEF2/D1,D2,D3,D4,D5,D6,D7,D8,D9,D10,D11,D12,SUMSRC
      COMMON/COEF3/NFTMX
C
  500 FORMAT(80A1)
  515 FORMAT(3F10.4,50X)
  510 FORMAT(10I3,50X)
  520 FORMAT(20X,3E15.6)
  530 FORMAT(20X,6E10.4)
  620 FORMAT(20X,4E15.6)
C
      IN=4
      READ(IN,510) NFTMX
      READ(IN,515) (REFE(IE),IE=1,3)
      READ(IN,515) (REFU(IU),IU=1,3)
C
      DO 100 NF=1,NFTMX
      READ(IN,500) TITLE
      DO 30 IU=1,3
      READ(IN,500)
      DO 20 IG=1,2
      READ(IN,520) (FLUX(IG,IE,IU),IE=1,3)
      READ(IN,520) (SIGA(IG,IE,IU),IE=1,3)
      READ(IN,520) (SIGF(IG,IE,IU),IE=1,3)
      READ(IN,520) (VN2(IG,IE,IU),IE=1,3)
      READ(IN,520) (DIFF(IG,IE,IU),IE=1,3)
      READ(IN,520) (SIG12(IG,IE,IU),IE=1,3)
   20 CONTINUE
C
      DO 25 IE=1,3
      READ(IN,530) (BT(IE,IU,IGR),IGR=1,6)
      DO 22 IGR=1,6
      IX=IGR+4
      XSC(IE,IU,IX)=BT(IE,IU,IGR)
   22 CONTINUE
   25 CONTINUE
   30 CONTINUE
C
      IF(ICASE.EQ.13.OR.ICASE.EQ.14.OR.ICASE.EQ.15) GO TO 37
      NX=10
      NG=1
      GO TO 39
   37 CONTINUE
      NX=11
      NG=2
      GO TO 41
   39 CONTINUE
C..............................................................................
C     * COLLAPSING TWO GROUP DATA TO ONE GROUP DATA
```

```
C..................................................................
      DO 40 IE=1,3
      DO 40 IU=1,3
      FL1=FLUX(1,IE,IU)
      FL2=FLUX(2,IE,IU)
      FLXX=FL1+FL2
      XSC(IE,IU,1)=(SIGA(1,IE,IU)*FL1+SIGA(2,IE,IU)*FL2)/FLXX
      XSC(IE,IU,2)=(SIGF(1,IE,IU)*FL1+SIGF(2,IE,IU)*FL2)/FLXX
      XSC(IE,IU,3)=(DIFF(1,IE,IU)*FL1+DIFF(2,IE,IU)*FL2)/FLXX
      XSC(IE,IU,4)=FLXX/(FL1/VN2(1,IE,IU)+FL2/VN2(2,IE,IU))
   40 CONTINUE
C
   41 CONTINUE
C
      DO 50 IG=1,NG
      IF(ICASE.EQ.13.OR.ICASE.EQ.14.OR.ICASE.EQ.15) GO TO 45
      GO TO 42
   45 CONTINUE
      DO 43 IE=1,3
      DO 43 IU=1,3
      XSC(IE,IU,1)=SIGA(IG,IE,IU)
      XSC(IE,IU,2)=SIGF(IG,IE,IU)
      XSC(IE,IU,3)=DIFF(IG,IE,IU)
      XSC(IE,IU,4)=VN2(IG,IE,IU)
      XSC(IE,IU,11)=SIG12(IG,IE,IU)
   43 CONTINUE
   42 CONTINUE
      DO 50 IX=1,NX
      C1(NF,IG,IX)=XSC(1,1,IX)
      C2(NF,IG,IX)=XSC(3,1,IX)-C1(NF,IG,IX)
      C3(NF,IG,IX)=XSC(1,3,IX)-C1(NF,IG,IX)
      C4(NF,IG,IX)=XSC(3,3,IX)-XSC(1,3,IX)
      C5(NF,IG,IX)=XSC(3,3,IX)-XSC(3,1,IX)
      C6(NF,IG,IX)=XSC(1,2,IX)-C1(NF,IG,IX)
      C7(NF,IG,IX)=XSC(3,2,IX)-XSC(1,2,IX)-C2(NF,IG,IX)
      C8(NF,IG,IX)=XSC(2,2,IX)-XSC(2,1,IX)-C6(NF,IG,IX)
      C9(NF,IG,IX)=C4(NF,IG,IX)-C2(NF,IG,IX)
      C10(NF,IG,IX)=XSC(2,3,IX)-XSC(2,1,IX)-C3(NF,IG,IX)
      C11(NF,IG,IX)=XSC(2,1,IX)-C1(NF,IG,IX)
   50 CONTINUE
C
C
   75 CONTINUE
  100 CONTINUE
C
      CON1=REFU(3)-REFU(2)
      CON2=REFU(3)-REFU(1)
      CON3=REFU(2)-REFU(1)
      D1=1./CON1/CON2
      D2=-1./CON1/CON3
      D3=REFU(1)*REFU(2)*D1
      D4=REFU(1)*REFU(3)*D2
      D5=-(REFU(1)+REFU(2))*D1
      D6=-(REFU(1)+REFU(3))*D2
      CON4=REFE(3)-REFE(2)
      CON5=REFE(3)-REFE(1)
      CON6=REFE(2)-REFE(1)
      D7=1./CON4/CON5
      D8=-1./CON4/CON6
      D9=REFE(1)*REFE(2)*D7
      D10=REFE(1)*REFE(3)*D8
      D11=-(REFE(1)+REFE(2))*D7
      D12=-(REFE(1)+REFE(3))*D8
C
      RETURN
      END
C
C
C
C
C*********************************************************************
      SUBROUTINE XDATA
C*********************************************************************
C
      REAL K1
      COMMON/SIM1/IMAX,JMAX,KMAX,ICASE,ISPEC,JSPEC,INUCLR,XKEFF
      COMMON/SIM2/JMX(20),NFT(15,15,30),AL(15,15),TAL(15,15),
     1            BAL(15,15),ASRC(15,15),SRC(15,15,30),AEXP(15,15),
     2            REXP(15,15,30),AXSRC(30),XXSRC(30)
      COMMON/SIM3/JJD(15,15),DZ1(200),DZ2(200),NF(200,30),NB(200),
     1            SC(200,30,6),XEXP(200,30),SIG1(200,30,11),
     2            CSIG1(200,30,11)
      COMMON/COEF1/C1(10,2,11),C2(10,2,11),C3(10,2,11),C4(10,2,11),
     1             C5(10,2,11),C6(10,2,11),C7(10,2,11),C8(10,2,11),
     2             C9(10,2,11),C10(10,2,11),C11(10,2,11)
      COMMON/COEF2/D1,D2,D3,D4,D5,D6,D7,D8,D9,D10,D11,D12,SUMSRC
      COMMON/DIM1/DX,DZT,RAMBDA(200),ALFA(200,30),BBLAMB(200)
      COMMON/TWOG1/SIG2(200,30,11),CSIG2(200,30,11),TFLX(2,4,30)
      COMMON/CONSS2/ NTOT(200),NBB(200),NBB1(200),NSP,N1PSP(200),
     1              K2PSP(200), NDP(200), NDP1(200), ISUB(200)
      COMMON/CONSS1/ QDIS(200,30), Q0(200,30), DZ(200,30),Z(200,30),
     1       K1(200,30), CKIN(200,30), ZETA(200,30), DOIN(200,30),
     2       DOOUT(200,30), ALPIN(200,30),BEE(200,30), CPI1(200,30),
     3       COR2PH(200,30), ZETSP(200,30), WIN
      COMMON/GKIN/IKIN,IDCHTY(15,15),ITY(225),JJMX(15),JJD8(15,15),
     @            ITY8(150)
C
      IF(ICASE.EQ.5.OR.ICASE.EQ.7.OR.ICASE.EQ.9) GO TO 25
      IL = 1
      IR = IMAX
      GO TO 26
  25  IL = ISPEC
      IR = ISPEC
  26  CONTINUE
C
      DO 80 I=IL,IR
      IF(ICASE.EQ.5.OR.ICASE.EQ.7.OR.ICASE.EQ.9) GO TO 60
      JL=1
      JR=JMX(I)
      GO TO 65
   60 JL=JSPEC
      JR=JSPEC
   65 CONTINUE
C
      DO 80 J=JL,JR
      M=JJD(I,J)
      MY=ITY(M)
      KK = 1
      DO 80 K=1,KMAX
      KP1=KK+1
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      IF(NTOT(MY) .EQ. KMAX) GO TO 20
      IF(NTOT(MY) .EQ. KMAX+1) GO TO 30
   20 U = ALFA(MY,K)
      GO TO 40
   30 IF(DZ(MY,KK) .LT. DZT) GO TO 50
      U = ALFA(MY,KK)
      GO TO 45
   50 U = (ALFA(MY,KK)*DZ(MY,KK) + ALFA(MY,KP1)*DZ(MY,KP1))/DZT
      GO TO 46
   45 KK = KK + 1
      GO TO 40
   46 KK = KK + 2
   40 U2=U*U
      N=NFT(I,J,K)
      G1E=D9+D11*REXP(I,J,K)+D7*REXP(I,J,K)**2
      G2E=D10+D12*REXP(I,J,K)+D8*REXP(I,J,K)**2
      F1U=D3+D5*U+D1*U2
      F2U=D4+D6*U+D2*U2
      DF1DU=D5+2.*D1*U
      DF2DU=D6+2.*D2*U
C
      NX=10
      IF(ICASE.EQ.13.OR.ICASE.EQ.14.OR.ICASE.EQ.15) NX=11
      DO 70 IX=1,NX
      FFA=C3(N,1,IX)+C9(N,1,IX)*G1E+C10(N,1,IX)*G2E
      FFB=C6(N,1,IX)+C7(N,1,IX)*G1E+C8(N,1,IX)*G2E
      SIG1(M,K,IX)=C1(N,1,IX)+C2(N,1,IX)*G1E+C11(N,1,IX)*G2E+
     1             F1U*FFA+F2U*FFB
      CSIG1(M,K,IX)=FFA*DF1DU+FFB*DF2DU
      IF(ICASE.EQ.13.OR.ICASE.EQ.14.OR.ICASE.EQ.15) GO TO 68
      GO TO 70
   68 CONTINUE
      FFA=C3(N,2,IX)+C9(N,2,IX)*G1E+C10(N,2,IX)*G2E
      FFB=C6(N,2,IX)+C7(N,2,IX)*G1E+C8(N,2,IX)*G2E
      SIG2(M,K,IX)=C1(N,2,IX)+C2(N,2,IX)*G1E+C11(N,2,IX)*G2E+
     1             F1U*FFA+F2U*FFB
      CSIG2(M,K,IX)=FFA*DF1DU+FFB*DF2DU
   70 CONTINUE
   80 CONTINUE
C
      RETURN
      END
C
C
C
C
C*****************************************************************
      SUBROUTINE COEF1(S,ICOUNT)
C*****************************************************************
C
C  *   THIS ROUTINE CALCULATES TEE, RHOX, RHOZ, RX, RZ, FOR
C      STEADY-STATE AND PERTURBED STATE(FUNCTION OF FREQUENCY)
C
      COMPLEX S,BR3,BR4,TEE
      DIMENSION BR2(15,15,30),CC(15,15,30),F22(15,15,30),
     1          ZZZ(15,15,30)
      COMMON/SIM1/IMAX,JMAX,KMAX,ICASE,ISPEC,JSPEC,INUCLR,XKEFF
      COMMON/SIM2/JMX(20),NFT(15,15,30),AL(15,15),TAL(15,15),
     1            BAL(15,15),ASRC(15,15),SRC(15,15,30),AEXP(15,15),
     2            REXP(15,15,30),AXSRC(30),XXSRC(30)
```

```
      COMMON/SIM3/JJD(15,15),DZ1(200),DZ2(200),NF(200,30),NB(200),
     1             SC(200,30,6),XEXP(200,30),SIG1(200,30,11),
     2             CSIG1(200,30,11)
      COMMON/SIM4/TEE(15,15,30)
      COMMON/SIM6/RHOX(15,15,30),RHOZ(15,15,30),RX(15,15,30),
     1             RZ(15,15,30),TEEO(15,15,30),PLAMDA(6), FPDF(15),
     2             FPLAM(15)
      COMMON/DIM1/DX,DZT,RAMBDA(200),ALFA(200,30),BBLAMB(200)
C
      IF(ICOUNT.EQ.1) GO TO 15
      IF(ICASE.EQ.1.OR.ICASE.EQ.3.OR.ICASE.EQ.7.OR.ICASE.EQ.9) GO TO 35
      IF(ICASE.EQ.11.OR.ICASE.EQ.12) GO TO 35
   15 CONTINUE
      DZZ=DZT*30.48
      A=0.3
      A3=3.*A
      AM=1.-A
C
      IF(ICASE.EQ.5.OR.ICASE.EQ.7.OR.ICASE.EQ.9) GO TO 16
      IL=1
      IR=IMAX
      GO TO 17
   16 IL=ISPEC
      IR=ISPEC
   17 CONTINUE
C
      DO 30 I=IL,IR
      IF(ICASE.EQ.5.OR.ICASE.EQ.7.OR.ICASE.EQ.9) GO TO 18
      JL=1
      JR=JMX(I)
      GO TO 19
   18 JL=JSPEC
      JR=JSPEC
   19 CONTINUE
C
      DO 30 J=JL,JR
      M=JJD(I,J)
C     WRITE(6,670) I,J,NB(M),DZ1(M),DZ2(M)
      DO 30 K=1,KMAX
      DZ=DZZ
      DF=SIG1(M,K,3)
      XOD25=.25/DF
      HOD=DZ*XOD25
      DXOD=DX*XOD25
      XO1D=1./(1.+DXOD)
      ZO1D=1./(1.+HOD)
      BR1=2.*XO1D/DX
      FA=ZO1D/DZ+BR1
      FB=XO1D/DX+2.*ZO1D/DZ
      XXK=SIG1(M,K,2)/SIG1(M,K,1)
      SIGA=SIG1(M,K,1)
      SIGF=SIG1(M,K,2)
      VL=SIG1(M,K,4)
      IF(INUCLR.EQ.1) GO TO 22
      R=DX*DX/DZ/DZ
      BDEN=A3+AM*(R+2.)
      XOB=1./BDEN
      BB=A3*XOB
      CC(I,J,K)=.25*AM*XOB
      F22(I,J,K)=BB+2.*CC(I,J,K)*(4.*XO1D+2.*R*ZO1D)
      QT=CC(I,J,K)*(SIGA-SIGF)/DF
      BR2(I,J,K)=FA+(SIGA-SIGF)*F22(I,J,K)
   22 CONTINUE
      RHOX(I,J,K)=(DXOD-1.)*XO1D
      RHOZ(I,J,K)=(HOD-1.)*ZO1D
      RX(I,J,K)=XO1D/DX/FA/2.
      RZ(I,J,K)=ZO1D/DZ/FB/2.
      IF(INUCLR.EQ.1) GO TO 25
      ZZZ(I,J,K)=2.*XO1D*DX+ZO1D*DZ
      TEEO(I,J,K)=(FA-QT*ZZZ(I,J,K))/BR2(I,J,K)
   23 TEE(I,J,K)=(TEEO(I,J,K)*BR2(I,J,K)-S*ZZZ(I,J,K)*CC(I,J,K)/
     1           SIG1(M,K,4)/SIG1(M,K,3))/(BR2(I,J,K)+S/SIG1(M,K,4)*
     2           F22(I,J,K))
      IF(ICOUNT.GT.1) GO TO 30
      TEEOO=TEEO(I,J,K)
      IF(TEEOO.EQ.1..AND.XXK.LT.1.) TEEO(I,J,K)=0.9999
      IF(TEEOO.EQ.1..AND.XXK.GE.1.) TEEO(I,J,K)=1.0001
      GO TO 30
   25 CONTINUE
      TEEO(I,J,K)=FA/(FA+SIGA-SIGF)
      TEE(I,J,K)=FA/(FA+SIGA+S/VL-SIGF)
      TEEOO=TEEO(I,J,K)
      IF(TEEOO.EQ.1..AND.XXK.LT.1.) TEEO(I,J,K)=0.9999
      IF(TEEOO.EQ.1..AND.XXK.GE.1.) TEEO(I,J,K)=1.0001
   30 CONTINUE
      IF(ICASE.NE.5) GO TO 35
      IF(ICOUNT.GT.1) GO TO 33
      IF(INRUN.GT.0) GO TO 35
C
      WRITE(6,600) (RHOX(ISPEC,JSPEC,K),K=4,19)
      WRITE(6,600) (RHOZ(ISPEC,JSPEC,K),K=4,19)
      WRITE(6,600) (RX(ISPEC,JSPEC,K),K=4,19)
      WRITE(6,600) (TEEO(ISPEC,JSPEC,K),K=4,19)
   33 WRITE(6,610) (TEE(ISPEC,JSPEC,K),K=5,9)
  600 FORMAT(1X,15F8.4)
  610 FORMAT(1X,10E12.5)
   35 CONTINUE
      RETURN
      END
C
C
C
C
C*********************************************************************
      SUBROUTINE KINET(S,ICOUNT,DELK,DELP,IVOCAL,CKCAAL)
C*********************************************************************
C
C     *  THIS ROUTINE GENERATES KINETICS PARAMETERS FOR ANY
C        GEOMETRIES
C
C
C    ***  ICASE = 1 POINT KINETICS(UNIFORM), CORE AVERAGE
C               = 2 POINT KINETICS(NON-UNIFORM RADIAL)
C               = 3 POINT KINETICS(NON-UNIFORM AXIAL)
C               = 4 RADIALLY COUPLED KINETICS(2-D)
C               = 5 AXIALLY COUPLED KINETICS(1-D), IDENTICAL CHANNEL
C               = 6 AXIALLY COUPLED KINETICS(1-D), AVERAGED CHANNEL
C               = 7 POINT KINETICS(NON-UNIFORM AXIAL), SPCEIFIC CHANNEL
C               = 8 GENERAL SPACE NODAL KINETICS(3-D)
C                   (CHECKER-BOARD PROBLEM ONLY)
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C                     = 9 POINT KINETICS(UNIFORM), SPECIFIC CHANNEL
C                     =10 RADIALLY COUPLED KINETICS(2-D)
C                         (CHECKER-BOARD PROBLEM ONLY)
C                     =11 POINT KINETICS(NON-UNIFORM RADIAL)
C                         (CHECKER-BOARD PROBLEM ONLY)
C                     =12 POINT KINETICS(UNIFORM CASE)
C                         (CHECKER-BOARD PROBLEM)
C                     =13 TWO GROUP AXIALLY COUPLED KINETICS, HOT CHANNEL
C                         (COARSE MESH DIFFUSION THEORY ONLY)
C                     =14 TWO GROUP CHECKER BOARD,  2-D
C                         (CMDT ONLY)
C                     =15 TWO GROUP CHECKER BOARD,  3-D
C                         (CMDT ONLY)
C
C
      REAL KF,KLOSS
      COMPLEX S,SUM1,SUM2,T,TT,SAIN,SANI,SAMR,AMN,ANM,AMR,RAIN,RANI,
     1        SAKN,SANK,RAIR,GAMN,GANM,PPSI,ZPK,ZPKP,AAA,B,ZPK1,TEE,
     2        XAIN,ZNI,XZNI,BI,RKI,XBM,XRKM,WW1,WW2,TZ1,TZ2,TWO,THREE
      COMPLEX TBI1(4,30),TBI2(4,30),TKI1(4,30),TKI2(4,30),TGI(4,30),
     1        TRIJ2(4,30,2),TZN1(4,30,2),TZN2(4,30,2),TFI(4,30),
     2        TRIJ1(4,30,2), CXK,CXXK,CXKN, CFP,SFP
      DIMENSION SUMBJ(6),DMDU(6),
     1    BBT(6),DBTDU(6),REAC(200),
     2    GTIME(200),CAL(200),XSGF(200),XVEL(200),CXGF(200),
     3    CXVL(200),CLAM(200),PBET(200,6),PBETA(6),
     4    CBETA(6),SUMBL(6),SUMCBL(6),SAION(6),SANOI(6),CBBT(6),
     5    AMON(6),ANOM(6),RBET(200,6),
     6    RAIOR(200),SAKON(2),SANOK(2),
     7    AXA(30),AXF(30),AV(30),ACXA(30),ACXF(30),ACV(30),
     8    SUMXRC(4),XKEF(200),XTFLX(2,4,30)
      DIMENSION BIJ01(4,30,2),BIJ02(4,30,2),DJOK1(4,30,2),DJOK2(4,30,2),
     1 DDC1(4,30,2),DDC2(4,30,2),DIJ01(4,30,2),DIJ02(4,30,2),
     2 DDOF1(4,30,2),DDOF2(4,30,2),TCXFJ1(4,30,2),TCXFJ2(4,30,2),
     3 TFLX1(4,30,2),TFLXT(4,30,2),TXFJ1(4,30,2),TXFJ2(4,30,2)
      DIMENSION XXA(4,2),XXF(4,2),XXD(4,2),XXV(4,2),XXR(4,2),
     1          CXXA(4,2),CXXF(4,2),CXXD(4,2),CXXV(4,2),CXXR(4,2),
     2          SUMB1(6),SUMCB1(6),SUMCB2(6),ATFLX(4,2)
C
      DIMENSION TO(200,30,6),XKN(200,30,6),XFS(200,30,6),
     8             CBET(200,6)
      DIMENSION R(200,30,6),RO(200,30,6),GAMON(200,30,6),
     8             RCBT(200,6),RAION(200,4)
      COMMON/CONST2/ P,VCH,VIN(200),AXS(200),DH(200),DHIN(200),
     1       PH(200),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2       DENSF,VFG1,RHOG,GO(200),GO2(200),HO(200),GC,G1,KLOSS(30),
     3       FRICMO(200),VGJH(200,30),COH(200,30),CZERO,VGJ,DPTS,
     4       GO2RF(200),HFG1,ZSP(30),NUMBSP(200,30),ALHEAT,CXF(200),
     5       CHFO,CHOMO1,CHOMO2,XKIN(200),XKEXIT(200)
C
      COMMON/SIM1/IMAX,JMAX,KMAX,ICASE,ISPEC,JSPEC,INUCLR,XKEFF
      COMMON/SIM2/JMX(20),NFT(15,15,30),AL(15,15),TAL(15,15),
     1             BAL(15,15),ASRC(15,15),SRC(15,15,30),AEXP(15,15),
     2             REXP(15,15,30),AXSRC(30),XXSRC(30)
      COMMON/SIM3/JJD(15,15),DZ1(200),DZ2(200),NF(200,30),NB(200),
     1             SC(200,30,6),XEXP(200,30),SIG1(200,30,11),
     2             CSIG1(200,30,11)
      COMMON/SIM4/TEE(15,15,30)
      COMMON/SIM5/RXA(15,15),RXF(15,15),RV(15,15),RCXF(15,15),
     1             RCXA(15,15),RCV(15,15)
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      COMMON/SIM6/RHOX(15,15,30),RHOZ(15,15,30),RX(15,15,30),
     1            RZ(15,15,30),TEED(15,15,30),PLAMDA(6), FPDF(15),
     2            FPLAM(15)
      COMMON/KIN1/XKINF(15,15,30),SIGF(15,15,30)
      COMMON/KIN2/RDF(15,15),RCDF(15,15),RANOI(200,4),ADF(30),
     1            ACDF(30),GANOM(200,30,6),CFP
      COMMON/KIN3/RANI(200,4),GANM(200,30,6),ZNI(200,4),BI(200)
      COMMON/KIN5/RKI(200),XZNI(200,30,6),XBM(200,30),XRKM(200,30)
      COMMON/PIKO/ZPK, ZPK1, ZPKP,DRDU,VOCAL
      COMMON/PTK1/AAA(200)
      COMMON/DIM1/DX,DZT,RAMBDA(200),ALFA(200,30),BBLAMB(200)
      COMMON/XX/T(200,30,6),SANI(6),SAIN(6),AMN(6),ANM(6),RAIR(200),
     1          RAIN(200,4),SAKN(2),SANK(2),GAMN(200,30,6)
      COMMON/TWOG1/SIG2(200,30,11),CSIG2(200,30,11),TFLX(2,4,30)
      COMMON/TWOG2/WW1(100,100),WW2(100,100),TZ1(100,100),
     1             TZ2(100,100),TWO(100,100),THREE(100,100)
      COMMON/TEST/CXK(15,15,30), CXKN(200,30,6)
C
C
      INRUN=1
  660 FORMAT(20X,'ICASE = ',I3)
  610 FORMAT(5X,10E12.5)
C     WRITE(6,660) ICASE
      DZ=DZT*30.48
      TSAR=DX*DX
      BSAR=TSAR
      VOL=DX*DX*DZ
      ANR=DX*DZ
      ANT=DX*DX
C
      IF(ICASE.EQ.13.OR.ICASE.EQ.14.OR.ICASE.EQ.15) GO TO 1785
C
      IF(ICASE.EQ.5.OR.ICASE.EQ.7.OR.ICASE.EQ.9) GO TO 88
      IL=1
      IR=IMAX
      GO TO 90
   88 IL=ISPEC
      IR=ISPEC
   90 CONTINUE
C
      JL=1
      DO 110 I=IL,IR
      IF(ICASE.EQ.5.OR.ICASE.EQ.7.OR.ICASE.EQ.9) GO TO 103
      JR=JMX(I)
      GO TO 105
  103 JL=JSPEC
      JR=JSPEC
  105 CONTINUE
C
      DO 110 J=JL,JR
        M=JJD(I,J)
      DO 110 K=1,KMAX
        SUM1 = CMPLX(0.,0.)
      DO 107 JJ=1,6
        MV = JJ + 4
        SUM1 = SUM1 + S*SIG1(M,K,MV)/(S + PLAMDA(JJ))
  107 CONTINUE
C     SIGA(I,J,K)=SIG1(M,K,1)
      SIGF(I,J,K)=SIG1(M,K,2)
      XKINF(I,J,K)=SIGF(I,J,K)/SIG1(M,K,1)
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      CXK(I,J,K) = XKINF(I,J,K) * (1.-SUM1) / (1.+S/SIG1(M,K,4)
     1                 /SIG1(M,K,1))
  110 CONTINUE
C.............................................................
C    * ADD THE FISSION PRODUCT EFFECT
C      CFP ; THE FACTOR OF F.P. EFFECT
C.............................................................
      SFP = CMPLX(0.,0.)
      TDF = 0.
      DO 106 I=1,11
      TDF = TDF + FPDF(I)
      SFP = SFP + FPLAM(I)*FPDF(I)/(S+FPLAM(I))
  106 CONTINUE
      CFP = 1.-TDF + SFP
C
      IF(ICOUNT.EQ.1) GO TO 40
      IF(ICASE.EQ.13.OR.ICASE.EQ.14.OR.ICASE.EQ.15) GO TO 1785
      IF(ICASE.EQ.1.OR.ICASE.EQ.2.OR.ICASE.EQ.3.OR.ICASE.EQ.7.OR.
     1 ICASE.EQ.9.OR.ICASE.EQ.11.OR.ICASE.EQ.12) GO TO 199
      GO TO 120
   40 CONTINUE
C
      DADU=0.
      DBDU=0.
      DCDU=0.
      DDDU=0.
      DEDU=0.
      DFDU=0.
      SUMA=0.
      SUMB=0.
      SUMC=0.
      SUMD=0.
      SUME=0.
      SUMF=0.
C
      DO 115 JJ=1,6
      SUMBJ(JJ)=0.
      DMDU(JJ)=0.
  115 CONTINUE
  120 CONTINUE
C
      IF(ICASE.EQ.5.OR.ICASE.EQ.7.OR.ICASE.EQ.9) GO TO 122
      IL=1
      IR=IMAX
      GO TO 123
  122 IL=ISPEC
      IR=ISPEC
  123 CONTINUE
C
      DO 200 I=IL,IR
      IM1=I-1
      IP1=I+1
      IF(ICASE.EQ.5.OR.ICASE.EQ.7.OR.ICASE.EQ.9) GO TO 124
      JL=1
      JR=JMX(I)
      GO TO 125
  124 JL=JSPEC
      JR=JSPEC
  125 CONTINUE
C
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```
      IF(I.GT.1) JIM1=JMX(IM1)
      DO 200 J=JL,JR
      JM1=J-1
      JP1=J+1
      M=JJD(I,J)
      AH=AL(I,J)
      BAH=BAL(I,J)
      TAH=TAL(I,J)
C
      DO 200 K=1,KMAX
      KM1=K-1
      KP1=K+1
C
      IF(ICASE.EQ.8.OR.ICASE.EQ.10.OR.ICASE.EQ.11) GO TO 155
      IF(ICASE.EQ.12) GO TO 155
      IF(ICASE.EQ.5.OR.ICASE.EQ.6.OR.ICASE.EQ.7.OR.ICASE.EQ.9) GO TO 176
C
C
      IF(I.NE.1) GO TO 130
  126 CONTINUE
      IF(I.EQ.1) GO TO 128
      IF(J.EQ.JR.AND.J.EQ.JIM1) GO TO 132
  128 CONTINUE
      IF(ICOUNT.GT.1) GO TO 135
      I(M,K,1)=CMPLX(0.,0.)
      SC(M,K,1)=0.
      TO(M,K,1)=0.
      R(M,K,1)=0.
      RO(M,K,1)=AH
      XKN(M,K,1)=1.
      CXKN(M,K,1) = CMPLX(1.,0.)
      XFS(M,K,1)=0.
      GO TO 135
  130 CONTINUE
C
      IF(J.EQ.JR) GO TO 126
      IF(J.LT.JR.AND.J.GT.JIM1) GO TO 126
  132 CONTINUE
C
C
      I(M,K,1)=IEE(IM1,J,K)
      CXKN(M,K,1) = CXK(IM1,J,K)
      IF(ICOUNT.GT.1) GO TO 135
      SC(M,K,1)=SRC(IM1,J,K)
      TO(M,K,1)=TEEO(IM1,J,K)
      R(M,K,1)=RX(IM1,J,K)
      RO(M,K,1)=RHOX(IM1,J,K)
      XKN(M,K,1)=XKINF(IM1,J,K)
      XFS(M,K,1)=SIGF(IM1,J,K)
  135 CONTINUE
C
      IF(J.NE.1) GO TO 137
      I(M,K,2)=IEE(I,J,K)
      CXKN(M,K,2) = CXK(I,J,K)
      IF(ICOUNT.GT.1) GO TO 140
      SC(M,K,2)=SRC(I,J,K)
      TO(M,K,2)=TEEO(I,J,K)
      R(M,K,2)=RX(I,J,K)
      RO(M,K,2)=RHOX(I,J,K)
      XKN(M,K,2)=XKINF(I,J,K)
      XFS(M,K,2)=SIGF(I,J,K)
      GO TO 140
  137 CONTINUE
C
      T(M,K,2)=TEE(I,JM1,K)
      CXKN(M,K,2) = CXK(I,JM1,K)
      IF(ICOUNT.GT.1) GO TO 140
      SC(M,K,2)=SRC(I,JM1,K)
      TO(M,K,2)=TEEO(I,JM1,K)
      R(M,K,2)=RX(I,JM1,K)
      RO(M,K,2)=RHOX(I,JM1,K)
      XKN(M,K,2)=XKINF(I,JM1,K)
      XFS(M,K,2)=SIGF(I,JM1,K)
  140 CONTINUE
C
      IF(I.NE.IMAX) GO TO 142
      T(M,K,3)=TEE(I,J,K)
      CXKN(M,K,3) = CXK(I,J,K)
      IF(ICOUNT.GT.1) GO TO 144
      SC(M,K,3)=SRC(I,J,K)
      TO(M,K,3)=TEEO(I,J,K)
      R(M,K,3)=RX(I,J,K)
      RO(M,K,3)=RHOX(I,J,K)
      XKN(M,K,3)=XKINF(I,J,K)
      XFS(M,K,3)=SIGF(I,J,K)
      GO TO 144
  142 CONTINUE
C
      T(M,K,3)=TEE(IP1,J,K)
      CXKN(M,K,3) = CXK(IP1,J,K)
      IF(ICOUNT.GT.1) GO TO 144
      SC(M,K,3)=SRC(IP1,J,K)
      TO(M,K,3)=TEEO(IP1,J,K)
      R(M,K,3)=RX(IP1,J,K)
      RO(M,K,3)=RHOX(IP1,J,K)
      XKN(M,K,3)=XKINF(IP1,J,K)
      XFS(M,K,3)=SIGF(IP1,J,K)
  144 CONTINUE
C
      IF(J.NE.JR) GO TO 146
      IF(ICOUNT.GT.1) GO TO 148
      SC(M,K,4)=0.
      TO(M,K,4)=0.
      T(M,K,4)=CMPLX(0.,0.)
      CXKN(M,K,4) = CMPLX(1.,0.)
      R(M,K,4)=0.
      RO(M,K,4)=AH
      XKN(M,K,4)=1.
      XFS(M,K,4)=0.
      GO TO 148
  146 CONTINUE
C
      T(M,K,4)=TEE(I,JP1,K)
      CXKN(M,K,4) = CXK(I,JP1,K)
      IF(ICOUNT.GT.1) GO TO 148
      SC(M,K,4)=SRC(I,JP1,K)
      TO(M,K,4)=TEEO(I,JP1,K)
      R(M,K,4)=RX(I,JP1,K)
      RO(M,K,4)=RHOX(I,JP1,K)
      XKN(M,K,4)=XKINF(I,JP1,K)
      XFS(M,K,4)=SIGF(I,JP1,K)
  148 CONTINUE
      GO TO 176
C
  155 CONTINUE
C.......................................................................
C     *  CHECKER-BOARD PROBLEM ONLY
C          (ICASE = 8, 10, OR 11)
C.......................................................................
      IF(I.NE.1) GO TO 160
  156 CONTINUE
      IF(I.EQ.1) GO TO 158
      IF(J.EQ.JR.AND.J.EQ.JIM1) GO TO 161
  158 CONTINUE
      T(M,K,1)=TEE(IP1,J,K)
      CXKN(M,K,1) = CXK(IP1,J,K)
      IF(ICOUNT.GT.1) GO TO 162
      SC(M,K,1)=SRC(IP1,J,K)
      TO(M,K,1)=TEEO(IP1,J,K)
      R(M,K,1)=RX(IP1,J,K)
      RO(M,K,1)=RHOX(IP1,J,K)
      XKN(M,K,1)=XKINF(IP1,J,K)
      XFS(M,K,1)=SIGF(IP1,J,K)
      GO TO 162
  160 CONTINUE
C
      IF(J.EQ.JR) GO TO 156
      IF(J.LT.JR.AND.J.GT.JIM1) GO TO 156
  161 CONTINUE
C
C
      T(M,K,1)=TEE(IM1,J,K)
      CXKN(M,K,1) = CXK(IM1,J,K)
      IF(ICOUNT.GT.1) GO TO 162
      SC(M,K,1)=SRC(IM1,J,K)
      TO(M,K,1)=TEEO(IM1,J,K)
      R(M,K,1)=RX(IM1,J,K)
      RO(M,K,1)=RHOX(IM1,J,K)
      XKN(M,K,1)=XKINF(IM1,J,K)
      XFS(M,K,1)=SIGF(IM1,J,K)
  162 CONTINUE
C
      IF(J.NE.1) GO TO 164
      T(M,K,2)=TEE(I,JP1,K)
      CXKN(M,K,2) = CXK(I,JP1,K)
      IF(ICOUNT.GT.1) GO TO 166
      SC(M,K,2)=SRC(I,JP1,K)
      TO(M,K,2)=TEEO(I,JP1,K)
      R(M,K,2)=RX(I,JP1,K)
      RO(M,K,2)=RHOX(I,JP1,K)
      XKN(M,K,2)=XKINF(I,JP1,K)
      XFS(M,K,2)=SIGF(I,JP1,K)
      GO TO 166
  164 CONTINUE
C
      T(M,K,2)=TEE(I,JM1,K)
      CXKN(M,K,2) = CXK(I,JM1,K)
      IF(ICOUNT.GT.1) GO TO 166
      SC(M,K,2)=SRC(I,JM1,K)
      TO(M,K,2)=TEEO(I,JM1,K)
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      R(M,K,2)=RX(I,JM1,K)
      RO(M,K,2)=RHOX(I,JM1,K)
      XKN(M,K,2)=XKINF(I,JM1,K)
      XFS(M,K,2)=SIGF(I,JM1,K)
  166 CONTINUE
C
      IF(I.NE.IMAX) GO TO 170
      T(M,K,3)=TEE(IM1,J,K)
      CXKN(M,K,3) = CXK(IM1,J,K)
      IF(ICOUNT.GT.1) GO TO 172
      SC(M,K,3)=SRC(IM1,J,K)
      TO(M,K,3)=TEEO(IM1,J,K)
      R(M,K,3)=RX(IM1,J,K)
      RO(M,K,3)=RHOX(IM1,J,K)
      XKN(M,K,3)=XKINF(IM1,J,K)
      XFS(M,K,3)=SIGF(IM1,J,K)
      GO TO 172
  170 CONTINUE
C
      T(M,K,3)=TEE(IP1,J,K)
      CXKN(M,K,3) = CXK(IP1,J,K)
      IF(ICOUNT.GT.1) GO TO 172
      SC(M,K,3)=SRC(IP1,J,K)
      TO(M,K,3)=TEEO(IP1,J,K)
      R(M,K,3)=RX(IP1,J,K)
      RO(M,K,3)=RHOX(IP1,J,K)
      XKN(M,K,3)=XKINF(IP1,J,K)
      XFS(M,K,3)=SIGF(IP1,J,K)
  172 CONTINUE
C
      IF(J.NE.JR) GO TO 174
      T(M,K,4)=TEE(I,JM1,K)
      CXKN(M,K,4) = CXK(I,JM1,K)
      IF(ICOUNT.GT.1) GO TO 176
      SC(M,K,4)=SRC(I,JM1,K)
      TO(M,K,4)=TEEO(I,JM1,K)
      R(M,K,4)=RX(I,JM1,K)
      RO(M,K,4)=RHOX(I,JM1,K)
      XKN(M,K,4)=XKINF(I,JM1,K)
      XFS(M,K,4)=SIGF(I,JM1,K)
      GO TO 176
  174 CONTINUE
C
      T(M,K,4)=TEE(I,JP1,K)
      CXKN(M,K,4) = CXK(I,JP1,K)
      IF(ICOUNT.GT.1) GO TO 176
      SC(M,K,4)=SRC(I,JP1,K)
      TO(M,K,4)=TEEO(I,JP1,K)
      R(M,K,4)=RX(I,JP1,K)
      RO(M,K,4)=RHOX(I,JP1,K)
      XKN(M,K,4)=XKINF(I,JP1,K)
      XFS(M,K,4)=SIGF(I,JP1,K)
  176 CONTINUE
      IF(ICASE.EQ.4.OR.ICASE.EQ.10) GO TO 200
C
      IF(K.NE.1) GO TO 180
      IF(ICOUNT.GT.1) GO TO 182
      SC(M,K,5)=0.
      TO(M,K,5)=0.
      T(M,K,5)=CMPLX(0.,0.)
      CXKN(M,K,5) = CMPLX(1.,0.)
      R(M,K,5)=0.
      RO(M,K,5)=BAH
      XKN(M,K,5)=1.
      XFS(M,K,5)=0.
      GO TO 182
  180 CONTINUE
C
      T(M,K,5)=TEE(I,J,KM1)
      CXKN(M,K,5) = CXK(I,J,KM1)
      IF(ICOUNT.GT.1) GO TO 182
      SC(M,K,5)=SRC(I,J,KM1)
      TO(M,K,5)=TEEO(I,J,KM1)
      R(M,K,5)=RZ(I,J,KM1)
      RO(M,K,5)=RHOZ(I,J,KM1)
      XKN(M,K,5)=XKINF(I,J,KM1)
      XFS(M,K,5)=SIGF(I,J,KM1)
  182 CONTINUE
C
      IF(K.NE.KMAX) GO TO 185
      IF(ICOUNT.GT.1) GO TO 188
      SC(M,K,6)=0.
      TO(M,K,6)=0.
      T(M,K,6)=CMPLX(0.,0.)
      CXKN(M,K,6) = CMPLX(1.,0.)
      R(M,K,6)=0.
      RO(M,K,6)=TAH
      XKN(M,K,6)=1.
      XFS(M,K,6)=0.
      GO TO 188
  185 CONTINUE
C
      T(M,K,6)=TEE(I,J,KP1)
      CXKN(M,K,6) = CXK(I,J,KP1)
      IF(ICOUNT.GT.1) GO TO 188
      SC(M,K,6)=SRC(I,J,KP1)
      TO(M,K,6)=TEEO(I,J,KP1)
      R(M,K,6)=RZ(I,J,KP1)
      RO(M,K,6)=RHOZ(I,J,KP1)
      XKN(M,K,6)=XKINF(I,J,KP1)
      XFS(M,K,6)=SIGF(I,J,KP1)
  188 CONTINUE
C
  200 CONTINUE
  199 CONTINUE
C
C
      ANT=DX*DX
      IF(ICASE.EQ.1.OR.ICASE.EQ.2.OR.ICASE.EQ.11) GO TO 201
      IF(ICASE.EQ.12) GO TO 201
      IF(ICASE.EQ.4.OR.ICASE.EQ.10) GO TO 305
      IF(ICASE.EQ.3.OR.ICASE.EQ.6.OR.ICASE.EQ.7.OR.ICASE.EQ.9) GO TO 405
      IF(ICASE.EQ.5.OR.ICASE.EQ.8) GO TO 705
C
  201 CONTINUE
C..................................................................
C  *   POINT KINETICS PARAMETERS(UNIFORM, OR NON-UNIFORM RADIAL)
C.................................................................
      IF(ICOUNT.GT.1) GO TO 303
      DO 300 I=1,IMAX
```

```fortran
      JR=JMX(I)
      DO 300 J=1,JR
      M=JJD(I,J)
      IF(ICASE.EQ.1.OR.ICASE.EQ.12) GO TO 204
      DADU=0.
      DBDU=0.
      DCDU=0.
      DDDU=0.
      DEDU=0.
      SUMA=0.
      SUMB=0.
      SUMC=0.
      SUMD=0.
      SUME=0.
C
      DO 203 JJ=1,6
      SUMBJ(JJ)=0.
      DMDU(JJ)=0.
  203 CONTINUE
  204 CONTINUE
C
      DO 295 K=1,KMAX
C.....................................................................
C  *   DEFINE TEMPORARY VARIABLES
C.....................................................................
      XK=XKINF(I,J,K)
      SSRC=SRC(I,J,K)
      SGF=SIG1(M,K,2)
      SOFX=SSRC/SGF
      SOSF=SOFX*SOFX
      V=SIG1(M,K,4)
      DVDU=CSIG1(M,K,4)
      VARU=(2./XK-1.)*CSIG1(M,K,2)-CSIG1(M,K,1)
C
      DO 208 JJ=1,6
      IX=JJ+4
      BBT(JJ)=SIG1(M,K,IX)
      DBTDU(JJ)=CSIG1(M,K,IX)
  208 CONTINUE
C.....................................................................
C  *   CALCULATION OF XLEAK(NET CURRENT ON 6 FACES OF NODE
C          (I,J,K)
C.....................................................................
      CURIN=0.
      CUROT=0.
      XLKI=SSRC*TEEO(I,J,K)/(TEEO(I,J,K)-1.)*(XK-1.)/XK
C
      DO 210 N=1,4
      XLKN=SC(M,K,N)*TO(M,K,N)/(TO(M,K,N)-1.)*(XKN(M,K,N)-1.)/
     1     XKN(M,K,N)
      CURIN=CURIN+XLKN*R(M,K,N)*(1.-RO(M,K,N))/(1.-RO(M,K,N)*
     1      RHOX(I,J,K))*ANR
      CUROT=CUROT+XLKI*RX(I,J,K)*(1.-RHOX(I,J,K))/(1.-RO(M,K,N)*
     1      RHOX(I,J,K))*ANR
  210 CONTINUE
C
      DO 215 N=5,6
      XLKN=SC(M,K,N)*TO(M,K,N)/(TO(M,K,N)-1.)*(XKN(M,K,N)-1.)/
     1     XKN(M,K,N)
      CURIN=CURIN+XLKN*R(M,K,N)*(1.-RO(M,K,N))/(1.-RO(M,K,N)*
     1         RHOZ(I,J,K))*ANT
      CUROT=CUROT+XLKI*RZ(I,J,K)*(1.-RHOZ(I,J,K))/(1.-RO(M,K,N)*
     1         RHOZ(I,J,K))*ANT
  215 CONTINUE
C
C
      XLEAK=CURIN-CUROT
C.................................................................
C  *  SUMMATION TO GET A, B, AND C OVER ALL DIRECTIONS
C.................................................................
      S2SF=SSRC*SOFX
      SUMA=SUMA+S2SF*(1.-1./XK)*VOL
      SUMB=SUMB+SOFX*XLEAK
      SUMC=SUMC+S2SF*VOL
      SUMD=SUMD+SOSF/V*VOL
      SUME=SUME+SOSF*VOL
C
      DO 220 JJ=1,6
      SUMBJ(JJ)=SUMBJ(JJ)+S2SF*BBT(JJ)*VOL
      DMDU(JJ)=DMDU(JJ)+SOSF*VOL*(SGF*DBTDU(JJ)-BBT(JJ)*
     1         CSIG1(M,K,2))
  220 CONTINUE
C.................................................................
C  *   DERIVATIVES OF A, B, C WRT VOID FRACTION
C.................................................................
      DADU=DADU+SOSF*VARU*VOL
      DBDU=DBDU-SOSF*CSIG1(M,K,2)*XLEAK/SSRC
      DCDU=DCDU-SOSF*CSIG1(M,K,2)*VOL
      DDDU=DDDU-(SOSF/V/V*DVDU+2.*SOSF/SGF/V*CSIG1(M,K,2))*VOL
      DEDU=DEDU-2.*SOSF/SGF*CSIG1(M,K,2)*VOL
  295 CONTINUE
C
      IF(ICASE.EQ.1.OR.ICASE.EQ.12) GO TO 298
      REAC(M)=(SUMA+SUMB)/SUMC
      XKEF(M)=1./(1.-REAC(M))
      GTIME(M)=SUMD/SUMC
      CAL(M)=(DADU+DBDU-REAC(M)*DCDU)/SUMC
      XSGF(M)=SUMC/SUME
      XVEL(M)=SUME/SUMD
      CXGF(M)=(DCDU-XSGF(M)*DEDU)/SUME
      CXVL(M)=(DEDU-XVEL(M)*DDDU)/SUMD
      CLAM(M)=(DDDU-GTIME(M)*DCDU)/SUMC
C
C     WRITE(6,610) REAC(M),GTIME(M),CAL(M),XSGF(M),CXGF(M),CXVL(M),
C    1             CLAM(M),XKEF(M)
      DO 297 JJ=1,6
      PBET(M,JJ)=(1.-REAC(M))*SUMBJ(JJ)/SUMC
      CBET(M,JJ)=((1.-REAC(M))*DMDU(JJ)-SUMBJ(JJ)*CAL(M)-
     1           PBET(M,JJ)*DCDU)/SUMC
  297 CONTINUE
  298 CONTINUE
  300 CONTINUE
C
      IF(ICASE.EQ.2.OR.ICASE.EQ.11) GO TO 302
      REACT=(SUMA+SUMB)/SUMC
      XKEFF=1./(1.-REACT)
      PCAPLA=SUMD/SUMC
      DRDU=(DADU+DBDU-REACT*DCDU)/SUMC
      CALPHA=(DADU+DBDU)/SUMC
      ASGI=SUMC/SUME
      AVEL=SUME/SUMD
      CSGF=(DCDU-ASGF*DEDU)/SUME
      CVL=(DEDU-AVEL*DDDU)/SUMD
      CLAMD=(DDDU-PCAPLA*DCDU)/SUMC
C
      DO 301 JJ=1,6
      PBETA(JJ)=SUMBJ(JJ)/SUMC
      CBETA(JJ)=(DMDU(JJ)-PBETA(JJ)*DCDU)/SUMC
  301 CONTINUE
  302 CONTINUE
C
      IF(ICASE.EQ.2.OR.ICASE.EQ.11) GO TO 303
      IF(IVOCAL.NE.0.) DRDU=CKCAAL
C     WRITE(6,610) REACT,PCAPLA,DRDU,CALPHA,ASGF,AVEL,CSGF,CVL,
C    1                 CLAMD,XKEFF
  303 CONTINUE
      IF(ICASE.EQ.1.OR.ICASE.EQ.12) GO TO 1000
      IF(ICASE.EQ.2.OR.ICASE.EQ.11) GO TO 1100
C
  305 CONTINUE
C.....................................................................
C  *  RADIALLY COUPLED KINETICS PARAMETERS CALCULATION(2-D)
C.....................................................................
      DO 350 I=1,IMAX
      JR=JMX(I)
      DO 350 J=1,JR
      M=JJD(I,J)
C
      DO 306 N=1,4
      SAIN(N)=CMPLX(0.,0.)
      SANI(N)=CMPLX(0.,0.)
      SAION(N)=0.
      SANOI(N)=0.
      SUMXRC(N)=0.
  306 CONTINUE
C
      SAMR=CMPLX(0.,0.)
      SAMOR=0.
      SUMSR=0.
      IF(ICOUNT.GT.1) GO TO 310
      SUMCDF=0.
      SUMCV=0.
      SUMCXA=0.
      SUMCXF=0.
      SUMDF=0.
      SUMV=0.
      SUMVV=0.
      SMTHE=0.
      SUMWW=0.
      SUMXA=0.
      SUMXX=0.
C
      DO 308 JJ=1,6
      SUMBL(JJ)=0.
      SUMCBL(JJ)=0.
  308 CONTINUE
  310 CONTINUE
C
      DO 340 K=1,KMAX
        CXXK = CXK(I,J,K)
      XK=XKINF(I,J,K)
      SSRC=SRC(I,J,K)
      DO 312 N=1,4
      SUMXRC(N)=SUMXRC(N)+SC(M,K,N)*VOL
  312 CONTINUE
      IF(ICOUNT.GT.1) GO TO 322
C.......................................................................
C   * DEFINE TEMPORARY VARIABLES
C.......................................................................
      V=SIG1(M,K,4)
      SGF=SIG1(M,K,2)
      DF=SIG1(M,K,3)
      SGA=SIG1(M,K,1)
      CV=CSIG1(M,K,4)
      CSGF=CSIG1(M,K,2)
      CSGA=CSIG1(M,K,1)
      CDF=CSIG1(M,K,3)
C
      DO 315 JJ=1,6
      IX=JJ+4
      BBT(JJ)=SIG1(M,K,IX)
      CBBT(JJ)=CSIG1(M,K,IX)
  315 CONTINUE
C
C
      SUMCV=SUMCV+SSRC*VOL*CV/SGF/V/V
      SUMV=SUMV+SSRC*VOL/SGF/V
      SUMSR=SUMSR+SSRC*VOL
      SMTHE=SMTHE+SSRC*VOL/SGF
      SUMXA=SUMXA+SSRC*VOL/XK
      SUMDF=SUMDF+SSRC*VOL*DF/SGF
      SUMCXF=SUMCXF+SSRC*VOL*CSGF/SGF/SGF
      SUMCXA=SUMCXA+SSRC*VOL*CSGA/SGF
      SUMCDF=SUMCDF+SSRC*VOL*CDF/SGF
      SUMXX=SUMXX+SSRC*VOL*CSGF/SGF/XK
      SUMVV=SUMVV+SSRC*VOL*CSGF/SGF/V/SGF
      SUMWW=SUMWW+SSRC*VOL*DF*CSGF/SGF/SGF
C
      DO 320 JJ=1,6
      SUMBL(JJ)=SUMBL(JJ)+SSRC*VOL*BBT(JJ)
      SUMCBL(JJ)=SUMCBL(JJ)+SSRC*VOL*CBBT(JJ)
  320 CONTINUE
C
  322 IF(ICOUNT.GT.1) SUMSR=SUMSR+SSRC*VOL
C
      DO 325 N=1,4
      XNU=ANR/(1.-RO(M,K,N)*RHOX(I,J,K))
      AMN(N)=TEE(I,J,K)/(TEE(I,J,K)-1.)*(CXXK-1.)/CXXK*RX(I,J,K)*
     1         (1.-RHOX(I,J,K))*XNU
      ANM(N)=T(M,K,N)/(T(M,K,N)-1.)*(CXKN(M,K,N)-1.)/CXKN(M,K,N)*
     1         R(M,K,N)*(1.-RO(M,K,N))*XNU
      AMON(N)=TEEO(I,J,K)/(TEEO(I,J,K)-1.)*(XK-1.)/XK*RX(I,J,K)*
     1         (1.-RHOX(I,J,K))*XNU
      ANOM(N)=TO(M,K,N)/(TO(M,K,N)-1.)*(XKN(M,K,N)-1.)/XKN(M,K,N)*
     1         R(M,K,N)*(1.-RO(M,K,N))*XNU
      SAIN(N)=SAIN(N)+AMN(N)*SSRC
      SANI(N)=SANI(N)+ANM(N)*SC(M,K,N)
      SAION(N)=SAION(N)+AMON(N)*SSRC
      SANOI(N)=SANOI(N)+ANOM(N)*SC(M,K,N)
  325 CONTINUE
```

```
C
      SAII=1.
      IF(K.EQ.1) SAII=BAII
      IF(K.EQ.KMAX) SAII=TAII
      AMR=TEE(I,J,K)/(TEE(I,J,K)-1.)*(CXXK-1.)/CXXK*RZ(I,J,K)*
     1    (1.-SAII)/(1.-SAII*RHOZ(I,J,K))*TSAR
      AMOR=TEEO(I,J,K)/(TEEO(I,J,K)-1.)*(XK-1.)/XK*RZ(I,J,K)*
     1    (1.-SAII)/(1.-SAII*RHOZ(I,J,K))*TSAR
      SAMR=SAMR+AMR*SSRC
      SAMOR=SAMOR+AMOR*SSRC
  335 CONTINUE
C
C
  340 CONTINUE
C
      IF(ICOUNT.GT.1) GO TO 344
C
      RXA(I,J)=SUMXA/SMTHE
      RXF(I,J)=SUMSR/SMTHE
      RV(I,J)=SMTHE/SUMV
      RCXF(I,J)=SUMCXF*RXF(I,J)/SMTHE
      RCXA(I,J)=(SUMCXA+RXA(I,J)*SUMCXF-SUMXX)/SMTHE
      RCV(I,J)=((SUMVV+SUMCV)*RV(I,J)-SUMCXF)/SUMV
      RDF(I,J)=SUMDF/SMTHE
      RCDF(I,J)=(SUMCDF+RDF(I,J)*SUMCXF-SUMWW)/SMTHE
C     WRITE(6,610) RXA(I,J),RXF(I,J),RV(I,J),RCXF(I,J),RCXA(I,J),
C    1              RCV(I,J),RDF(I,J),RCDF(I,J)
C
      DO 343 JJ=1,6
      RBET(M,JJ)=SUMBL(JJ)/SUMSR
      RCBT(M,JJ)=SUMCBL(JJ)/SUMSR
  343 CONTINUE
  344 CONTINUE
C
      RAIR(M)=SAMR/SUMSR
      RAIOR(M)=SAMOR/SUMSR
C
      DO 346 N=1,4
      IF(SUMXRC(N).EQ.0.) SUMXRC(N)=1.
      RAIN(M,N)=SAIN(N)/SUMSR
      RANI(M,N)=SANI(N)/SUMXRC(N)
      RAION(M,N)=SAION(N)/SUMSR
      RANOI(M,N)=SANOI(N)/SUMXRC(N)
  346 CONTINUE
C
  350 CONTINUE
C...............................................................
C  *   RADIALLY COUPLED KINETICS(2-D)
C...............................................................
      DO 395 I=1,IMAX
      IM1=I-1
      IP1=I+1
      IF(I.GT.1) JIM1=JMX(IM1)
      JR=JMX(I)
      DO 395 J=1,JR
      M=JJD(I,J)
      JM1=J-1
      JP1=J+1
      SUM1=CMPLX(0.,0.)
      SUM2=CMPLX(0.,0.)
```

```
C
      DO 355 JJ=1,6
      SUM1=SUM1+S*RBET(M,JJ)/(S+PLAMDA(JJ))
      SUM2=SUM2+S*RCBT(M,JJ)/(S+PLAMDA(JJ))
  355 CONTINUE
C
      XAIN=CMPLX(0.,0.)
      XAION=0.
C
      DO 390 N=1,4
      XAIN=XAIN+RAIN(M,N)
      XAION=XAION+RAION(M,N)
      IF(N.EQ.1) GO TO 361
      IF(N.EQ.2) GO TO 364
      IF(N.EQ.4) GO TO 365
      IF(N.EQ.3) GO TO 366
  361 IF(I.EQ.1) GO TO 362
C
      IF(J.GT.JIM1.AND.J.LE.JR) GO TO 362
      ZNI(M,N)=RCXF(IM1,J)/RXF(IM1,J)*RANI(M,N)
      GO TO 390
  362 ZNI(M,N)=CMPLX(0.,0.)
      IF(ICASE.EQ.10) ZNI(M,N)=RCXF(IP1,J)/RXF(IP1,J)*RANI(M,N)
      GO TO 390
C
  364 IF(J.NE.1) ZNI(M,N)=RCXF(I,JM1)/RXF(I,JM1)*RANI(M,N)
      IF(J.EQ.1.AND.ICASE.EQ.10) ZNI(M,N)=RCXF(I,JP1)/RXF(I,JP1)*
     1                                     RANI(M,N)
      IF(J.EQ.1.AND.ICASE.EQ.4) ZNI(M,N)=RCXF(I,J)/RXF(I,J)*
     1                                    RANI(M,N)
      GO TO 390
C
  365 IF(J.EQ.JR.AND.ICASE.EQ.10) ZNI(M,N)=RCXF(I,JM1)/RXF(I,JM1)*
     1                                      RANI(M,N)
      IF(J.EQ.JR.AND.ICASE.EQ.4) ZNI(M,N)=CMPLX(0.,0.)
      IF(J.NE.JR) ZNI(M,N)=RCXF(I,JP1)/RXF(I,JP1)*RANI(M,N)
      GO TO 390
  366 IF(I.EQ.IMAX.AND.ICASE.EQ.10) ZNI(M,N)=RCXF(IM1,J)/RXF(IM1,J)*
     1                                        RANI(M,N)
      IF(I.EQ.IMAX.AND.ICASE.EQ.4) ZNI(M,N)=RCXF(I,J)/RXF(I,J)*
     1                                       RANI(M,N)
      IF(I.NE.IMAX) ZNI(M,N)=RCXF(IP1,J)/RXF(IP1,J)*RANI(M,N)
  390 CONTINUE
C
C
      BI(M)=(RXA(I,J)+S/RV(I,J))/RXF(I,J)+RAIR(M)+(SUM1-1.)/XKEFF+
     1      XAIN
      RKI(M)=((1.-SUM1)/XKEFF+BI(M))*RCXF(I,J)/RXF(I,J)-SUM2/XKEFF-
     1        (RAIOR(M)+XAION)*RCDF(I,J)/RDF(I,J)-
     2        (RCXA(I,J)-S*RCV(I,J)/RV(I,J)**2)/RXF(I,J)
  395 CONTINUE
C
C
      GO TO 2000
C
  405 CONTINUE
C..........................................................................
C  *  POINT KINETICS(FOR NON-UNIFORM AXIAL, OR SPECIFIC CHANNEL),
C     OR AXIALLY COUPLED KINETICS(AVERAGE CHANNEL)
C        (ICASE=3, 6, OR 7)
```

```
C..................................................................
      I37=0
      IF(ICASE.EQ.3.OR.ICASE.EQ.7.OR.ICASE.EQ.9) I37=1
      IF(ICOUNT.GT.1.AND.I37.EQ.1) GO TO 485
      DO 480 K=1,KMAX
      IF(ICASE.EQ.3.OR.ICASE.EQ.7.OR.ICASE.EQ.9) GO TO 408
      DO 406 N=1,2
      SAKN(N)=CMPLX(0.,0.)
      SANK(N)=CMPLX(0.,0.)
      SAKON(N)=0.
      SANOK(N)=0.
      SUMXRC(N)=0.
  406 CONTINUE
C
      SAMR=CMPLX(0.,0.)
      SAMOR=0.
      SUMSR=0.
      IF(ICOUNT.GT.1) GO TO 410
      SUMCDF=0.
      SUMCV=0.
      SUMCXA=0.
      SUMCXF=0.
      SUMDF=0.
      SUMV=0.
      SUMVV=0.
      SMTHE=0.
      SUMWW=0.
      SUMXA=0.
      SUMXX=0.
C
      DO 407 JJ=1,6
      SUMBL(JJ)=0.
      SUMCBL(JJ)=0.
  407 CONTINUE
C
      GO TO 410
  408 CONTINUE
C..................................................................
C *  ICASE=3  POINT KINETICS, NON-UNIFORM AXIAL
C..................................................................
      IF(ICASE.EQ.9) GO TO 410
      DADU=0.
      DBDU=0.
      DCDU=0.
      DDDU=0.
      DFDU=0.
      DIDU=0.
      SUMA=0.
      SUMB=0.
      SUMC=0.
      SUMD=0.
      SUME=0.
      SUMF=0.
C
      DO 409 JJ=1,6
      SUMBJ(JJ)=0.
      DMDU(JJ)=0.
  409 CONTINUE
C
  410 CONTINUE
```

```
      IF(ICASE.EQ.7.OR.ICASE.EQ.9) GO TO 411
      IL=1
      IR=IMAX
      GO TO 412
  411 IL=ISPEC
      IR=ISPEC
  412 CONTINUE
      JL=1
      IF(ICASE.EQ.7.OR.ICASE.EQ.9) JL=JSPEC
      DO 470 I=IL,IR
      IM1=I-1
      IF(I.GT.1) JIM1=JMX(IM1)
      JR=JMX(I)
      IF(ICASE.EQ.7.OR.ICASE.EQ.9) JR=JSPEC
      SUMXRC(1)=0.
      SUMXRC(2)=0.
      DO 470 J=JL,JR
        CXXK = CXK(I,J,K)
      M=JJD(I,J)
      SSRC=SRC(I,J,K)
      IF(K.NE.1) SUMXRC(1)=SUMXRC(1)+SC(M,K,5)*VOL
      IF(K.NE.KMAX) SUMXRC(2)=SUMXRC(2)+SC(M,K,6)*VOL
      XK=XKINF(I,J,K)
      IF(ICOUNT.GT.1) GO TO 446
C.....................................................................
C  *  DEFINE TEMPORARY VARIABLES
C.....................................................................
      V=SIG1(M,K,4)
      SGF=SIG1(M,K,2)
      DF=SIG1(M,K,3)
      SGA=SIG1(M,K,1)
      CV=CSIG1(M,K,4)
      CSGF=CSIG1(M,K,2)
      CSGA=CSIG1(M,K,1)
      CDF=CSIG1(M,K,3)
      VARU=(2./XK-1.)*CSIG1(M,K,2)-CSIG1(M,K,1)
C
      DO 420 JJ=1,6
      IX=JJ+4
      BBT(JJ)=SIG1(M,K,IX)
      CBBT(JJ)=CSIG1(M,K,IX)
      DBTDU(JJ)=CBBT(JJ)
  420 CONTINUE
C
      SOFX=SSRC/SGF
      SOSF=SOFX*SOFX
C
      IF(ICASE.EQ.6) GO TO 440
C.....................................................................
C  *  CALCULATION OF POINT KINETICS PARAMETERS FOR NON-UNIFORM
C     AXIAL CASE
C.....................................................................
      CURIN=0.
      CUROT=0.
      XLKI=SSRC*TEEO(I,J,K)/(TEEO(I,J,K)-1.)*(XK-1.)/XK
C
      IF(ICASE.EQ.7.OR.ICASE.EQ.9) GO TO 426
C
      DO 425 N=1,4
      XLKN=SC(M,K,N)*TO(M,K,N)/(TO(M,K,N)-1.)*(XKN(M,K,N)-1.)/
```

```
     1      XKN(M,K,N)
      CURIN=CURIN+XLKN*R(M,K,N)*(1.-RO(M,K,N))/(1.-RO(M,K,N)*
     1       RHOX(I,J,K))*ANR
      CUROT=CUROT+XLKI*RX(I,J,K)*(1.-RHOX(I,J,K))/(1.-RO(M,K,N)*
     1       RHOX(I,J,K))*ANR
  425 CONTINUE
C
  426 CONTINUE
      DO 430 N=5,6
      XLKN=SC(M,K,N)*TO(M,K,N)/(TO(M,K,N)-1.)*(XKN(M,K,N)-1.)/
     1      XKN(M,K,N)
      CURIN=CURIN+XLKN*R(M,K,N)*(1.-RO(M,K,N))/(1.-RO(M,K,N)*
     1       RHOZ(I,J,K))*ANT
      CUROT=CUROT+XLKI*RZ(I,J,K)*(1.-RHOZ(I,J,K))/(1.-RO(M,K,N)*
     1       RHOZ(I,J,K))*ANT
  430 CONTINUE
C
      XLEAK=CURIN-CUROT
C.......................................................................
C  *  SUMMATION TO GET A, B, AND C OVER ALL DIRECTIONS
C.......................................................................
      S2SF=SSRC*SOFX
      SUMA=SUMA+S2SF*(1.-1./XK)*VOL
      SUMB=SUMB+SOFX*XLEAK
      SUMC=SUMC+S2SF*VOL
      SUMD=SUMD+SOSF/V*VOL
      SUME=SUME+SOSF*VOL
      SUMF=SUMF+SGA*SOSF*VOL
C
      DO 435 JJ=1,6
      SUMBJ(JJ)=SUMBJ(JJ)+S2SF*BBT(JJ)*VOL
      DMDU(JJ)=DMDU(JJ)+SOSF*VOL*(SGF*DBTDU(JJ)-BBT(JJ)*
     1          CSIG1(M,K,2))
  435 CONTINUE
C.......................................................................
C  *   DERIVATIVES OF A, B, C WRT VOID FRACTION
C.......................................................................
      DADU=DADU+SOSF*VARU*VOL
      DBDU=DBDU-SOSF*CSIG1(M,K,2)*XLEAK/SSRC
      DCDU=DCDU-SOSF*CSIG1(M,K,2)*VOL
      DDDU=DDDU-(SOSF/V/V*CV+2.*SOSF/SGF/V*CSIG1(M,K,2))*VOL
      DEDU=DEDU-2.*SOSF/SGF*CSIG1(M,K,2)*VOL
      DFDU=DFDU+SOSF*VOL*(CSGA-2./XK*CSGF)
      GO TO 470
  440 CONTINUE
C
      SUMCV=SUMCV+SSRC*VOL*CV/SGF/V/V
      SUMV=SUMV+SSRC*VOL/SGF/V
      SUMSR=SUMSR+SSRC*VOL
      SMTHE=SMTHE+SSRC*VOL/SGF
      SUMXA=SUMXA+SSRC*VOL/XK
      SUMDF=SUMDF+SSRC*VOL*DF/SGF
      SUMCXF=SUMCXF+SSRC*VOL*CSGF/SGF/SGF
      SUMCXA=SUMCXA+SSRC*VOL*CSGA/SGF
      SUMCDF=SUMCDF+SSRC*VOL*CDF/SGF
      SUMXX=SUMXX+SSRC*VOL*CSGF/SGF/XK
      SUMVV=SUMVV+SSRC*VOL*CSGF/SGF/V/SGF
      SUMWW=SUMWW+SSRC*VOL*DF*CSGF/SGF/SGF
C
      DO 445 JJ=1,6
```

```
          SUMBL(JJ)=SUMBL(JJ)+SSRC*VOL*BBT(JJ)
          SUMCBL(JJ)=SUMCBL(JJ)+SSRC*VOL*CBBT(JJ)
  445 CONTINUE
  446 IF(ICASE.EQ.6.AND.ICOUNT.GT.1) SUMSR=SUMSR+SSRC*VOL
C
C
      DO 448 NN=1,2
      N=NN+4
      XNU=ANI/(1.-RO(M,K,N)*RHOZ(I,J,K))
      AMN(NN)=TEE(I,J,K)/(TEE(I,J,K)-1.)*(CXXK-1.)/CXXK*RZ(I,J,K)*
     1        (1.-RHOZ(I,J,K))*XNU
      ANM(NN)=T(M,K,N)/(T(M,K,N)-1.)*(CXKN(M,K,N)-1.)/CXKN(M,K,N)*
     1        R(M,K,N)*(1.-RO(M,K,N))*XNU
      AMON(NN)=TEEO(I,J,K)/(TEEO(I,J,K)-1.)*(XK-1.)/XK*RZ(I,J,K)*
     1        (1.-RHOZ(I,J,K))*XNU
      ANOM(NN)=TO(M,K,N)/(TO(M,K,N)-1.)*(XKN(M,K,N)-1.)/XKN(M,K,N)*
     1        R(M,K,N)*(1.-RO(M,K,N))*XNU
      SAKN(NN)=SAKN(NN)+AMN(NN)*SSRC
      SANK(NN)=SANK(NN)+ANM(NN)*SC(M,K,N)
      SAKON(NN)=SAKON(NN)+AMON(NN)*SSRC
      SANOK(NN)=SANOK(NN)+ANOM(NN)*SC(M,K,N)
  448 CONTINUE
C
      IF(ICASE.GT.1) GO TO 449
C     WRITE(10,9999) I,J,K,AMN(1),AMN(2),ANM(1),ANM(2),TEE(I,J,K),XK,
C    1              XNU
 9999 FORMAT(1X,3I3,1X,12E10.3)
  449 CONTINUE
C
      IF(I.EQ.1) GO TO 450
      IF(J.EQ.JR.OR.J.GT.JIM1) GO TO 450
      GO TO 460
  450 CONTINUE
      SAR=ANR
      AII=AL(I,J)
      IF(J.EQ.JR) SAR=2.*ANR
      IF(I.EQ.1) GO TO 453
      IF(J.EQ.JR.AND.J.EQ.JIM1) SAR=ANR
  453 CONTINUE
      AMR=TEE(I,J,K)/(TEE(I,J,K)-1.)*(CXXK-1.)/CXXK*RX(I,J,K)*
     1    (1.-AII)/(1.-AII*RHOX(I,J,K))*SAR
      AMOR=TEEO(I,J,K)/(TEEO(I,J,K)-1.)*(XK-1.)/XK*RX(I,J,K)*
     1    (1.-AII)/(1.-AII*RHOX(I,J,K))*SAR
      SAMR=SAMR+AMR*SSRC
      SAMOR=SAMOR+AMOR*SSRC
  460 CONTINUE
C
  470 CONTINUE
C
      IF(ICASE.EQ.6) GO TO 473
      IF(ICASE.EQ.9) GO TO 480
      REAC(K)=(SUMA+SUMB)/SUMC
      XKEF(K)=1./(1.-REAC(K))
      GTIME(K)=SUMD/SUMC
      CAL(K)=(DADU+DBDU-REAC(K)*DCDU)/SUMC
      XSGF(K)=SUMC/SUME
      XVEL(K)=SUME/SUMD
      CXGF(K)=(DCDU-XSGF(K)*DEDU)/SUME
      CXVL(K)=(DEDU-XVEL(K)*DDDU)/SUMD
      CLAM(K)=(DDDU-GTIME(K)*DCDU)/SUMC
```

```
C
      IF(INRUN.GT.0) GO TO 4870
C     WRITE(6,610) REAC(K),GTIME(K),CAL(K),XSGF(K),XVEL(K),CXGF(K),
C    1               CXVL(K),CLAM(K),XKEF(K)
 4870 CONTINUE
      DO 472 JJ=1,6
      PBET(K,JJ)=(1.-REAC(K))*SUMBJ(JJ)/SUMC
      CBET(K,JJ)=((1.-REAC(K))*DMDU(JJ)-SUMBJ(JJ)*CAL(K)-
     1              PBET(K,JJ)*DCDU)/SUMC
  472 CONTINUE
  473 CONTINUE
      IF(ICOUNT.GT.1) GO TO 477
C
      IF(ICASE.EQ.3.OR.ICASE.EQ.7) GO TO 476
      AXA(K)=SUMXA/SMTHE
      AXF(K)=SUMSR/SMTHE
      AV(K)=SMTHE/SUMV
      ACXF(K)=SUMCXF*AXF(K)/SMTHE
      ACXA(K)=(SUMCXA+AXA(K)*SUMCXF-SUMXX)/SMTHE
      ACV(K)=((SUMVV+SUMCV)*AV(K)-SUMCXF)/SUMV
      ADF(K)=SUMDF/SMTHE
      ACDF(K)=(SUMCDF+ADF(K)*SUMCXF-SUMWW)/SMTHE
C
      IF(INRUN.GT.0) GO TO 4890
C     WRITE(6,610) AXA(K),AXF(K),AV(K),ACXF(K),ACXA(K),ACV(K),
C    1               ADF(K),ACDF(K)
 4890 CONTINUE
      DO 474 JJ=1,6
      RBET(K,JJ)=SUMBL(JJ)/SUMSR
      RCBT(K,JJ)=SUMCBL(JJ)/SUMSR
  474 CONTINUE
  477 CONTINUE
C
      RAIR(K)=SAMR/SUMSR
      RAIOR(K)=SAMOR/SUMSR
C
      IF(K.EQ.1) SUMXRC(1)=1.
      IF(K.EQ.KMAX) SUMXRC(2)=1.
      DO 475 N=1,2
      RAIN(K,N)=SAKN(N)/SUMSR
      RANI(K,N)=SANK(N)/SUMXRC(N)
      RAION(K,N)=SAKON(N)/SUMSR
      RANOI(K,N)=SANOK(N)/SUMXRC(N
  475 CONTINUE
C     WRITE(10,9991)
 9991 FORMAT(2X,'  K,  SAMR(CMPLX),  SUMSR,  SAMOR,  RAIOR,  RAIR,
     1  RAIN(K,1),  RAIN(K,2)')
C     WRITE(10,9997) K,SAMR,SUMSR,SAMOR,RAIOR(K),RAIR(K),RAIN(K,1),
C    1               RAIN(K,2)
 9997 FORMAT(2X,I3,11E11.4)
  476 CONTINUE
  480 CONTINUE
      IF(ICASE.NE.9) GO TO 485
      REACT=(SUMA+SUMB)/SUMC
      PCAPLA=SUMD/SUMC
      DRDU=(DADU+DBDU-REACT*DCDU)/SUMC
      CALPHA=(DADU+DBDU)/SUMC
      ASGF=SUMC/SUME
      ASGA=SUMF/SUME
      AVEL=SUME/SUMD
      CSGF=(DCDU-ASGF*DEDU)/SUME
      CSA=(DFDU-ASGA*DEDU)/SUME
      CVL=(DEDU-AVEL*DDDU)/SUMD
      CLAMD=(DDDU-PCAPLA*DCDU)/SUMC
      IF(IVOCAL.NE.0.) DRDU=CKCAAL
      DO 490 JJ=1,6
      PBETA(JJ)=SUMBJ(JJ)/SUMC*(1.-REACT)
      CBETA(JJ)=((1.-REACT)*DMDU(JJ)-SUMBJ(JJ)*DRDU-PBETA(JJ)*DCDU)/SUMC
  490 CONTINUE
      IF(INRUN .GT. 0)GO TO 485
C     WRITE(6,671) REACT,PCAPLA,DRDU,CALPHA,ASGF,AVEL,CSGF,CVL,
C    1             CLAMD,ASGA,CSA
  671 FORMAT(5X,'REACT',5X,'PCAPLA',5X,'DRDU',5X,'CALPHA',5X,'ASGF',
     1       5X,'AVEL',5X,'CSGF',5X,'CVL',5X,'CLAMD',5X,'ASGA',5X,
     2       'CSA',//,5X,11E11.4)
  485 CONTINUE
      IF(ICASE.EQ.9) GO TO 1000
      GO TO 1199
  705 CONTINUE
C...........................................................................
C  *  GENERAL SPACE KINETICS(3-D) OR AXIALLY COUPLED KINETICS
C       (1-D, IDENTICAL CHANNEL) PARAMETERS CALCULATION
C...........................................................................
      IF(ICASE.EQ.8) GO TO 706
      IL=ISPEC
      IRR=ISPEC
      GO TO 708
  706 IL=1
      IRR=IMAX
  708 CONTINUE
C
      DO 760 I=IL,IRR
      IF(ICASE.EQ.8) GO TO 710
      JL=JSPEC
      JR=JSPEC
      GO TO 715
  710 JL=1
      JR=JMX(I)
  715 CONTINUE
C
      DO 760 J=JL,JR
      M=JJD(I,J)
      DO 760 K=1,KMAX
C
        CXXK = CXK(I,J,K)
      XK=XKINF(I,J,K)
      XTO=TEFO(I,J,K)
      XRO=RHOX(I,J,K)
      ZRO=RHOZ(I,J,K)
      XR=RX(I,J,K)
      ZR=RZ(I,J,K)
C
      IF(ICASE.EQ.5) GO TO 745
C
      DO 740 N=1,4
      GAMN(M,K,N)=TEE(I,J,K)/(TEE(I,J,K)-1.)*(CXXK-1.)/CXXK*XR*
     1       (1.-XRO)/(1.-XRO*RO(M,K,N))*ANR/VOL
      GANM(M,K,N)=T(M,K,N)/(T(M,K,N)-1.)*(CXKN(M,K,N)-1.)/CXKN(M,K,N)*
     1       R(M,K,N)*(1.-RO(M,K,N))/(1.-XRO*RO(M,K,N))*
     2       ANR/VOL
```

```
      IF(ICOUNT.GT.1) GO TO 740
      GAMON(M,K,N)=XTO/(XTO-1.)*(XK-1.)/XK*XR*(1.-XRO)/(1.-XRO*
     1        RO(M,K,N))*ANR/VOL
      GANOM(M,K,N)=TO(M,K,N)/(TO(M,K,N)-1.)*(XKN(M,K,N)-1.)/
     1        XKN(M,K,N)*R(M,K,N)*(1.-RO(M,K,N))/(1.-RO(M,K,N)*
     2        XRO)*ANR/VOL
  740 CONTINUE
  745 CONTINUE
C
      DO 750 NN=5,6
      N=NN
      IF(ICASE.EQ.5) N=NN-4
      GAMN(M,K,N)=TEE(I,J,K)/(TEE(I,J,K)-1.)*(CXXK-1.)/CXXK*ZR*
     1        (1.-ZRO)/(1.-ZRO*RO(M,K,NN))*ANT/VOL
      GANM(M,K,N)=T(M,K,NN)/(T(M,K,NN)-1.)*(CXKN(M,K,NN)-1.)/
     1   CXKN(M,K,NN)* R(M,K,NN)*(1.-RO(M,K,NN))/(1.-ZRO*RO(M,K,NN))*
     2   ANT/VOL
      IF(ICOUNT.GT.1) GO TO 750
      GAMON(M,K,N)=XTO/(XTO-1.)*(XK-1.)/XK*ZR*(1.-ZRO)/(1.-ZRO*
     1        RO(M,K,NN))*ANT/VOL
      GANOM(M,K,N)=TO(M,K,NN)/(TO(M,K,NN)-1.)*(XKN(M,K,NN)-1.)/
     1        XKN(M,K,NN)*R(M,K,NN)*(1.-RO(M,K,NN))/(1.-RO(M,K,NN)*
     2        ZRO)*ANT/VOL
  750 CONTINUE
  760 CONTINUE
      IF(ICASE.EQ.5) GO TO 1400
      IF(ICASE.EQ.8) GO TO 1700
C
 1000 CONTINUE
      IF(IVOCAL.NE.0.) DRDU=CKCAAL
C..............................................................
C  * ZERO POWER POINT KINETICS(UNIFORM)
C..............................................................
      SUM1=CMPLX(0.,0.)
      SUM2=CMPLX(0.,0.)
C
      DO 1070 I=1,6
      SUM1=SUM1+PBETA(I)*S/(S+PLAMDA(I))
      SUM2=SUM2+CBETA(I)*S/(S+PLAMDA(I))
 1070 CONTINUE
      PPSI=SUM1/PCAPLA
C
      IF(DELK .NE. 0.) GO TO 1092
      IF(ICASE.EQ.9) GO TO 1091
      ZPK=CHFO/PCAPLA/(PPSI+S)
      ZPKP=CHFO*(CSGF/ASGF+CVL/AVEL)+ZPK*(DRDU-SUM2+PPSI*CLAMD)
      ZPKP = CFP*ZPKP
      ZPK1=ZPK
      ZPK=DRDU*ZPK1
 1090 CONTINUE
C
      GO TO 2000
 1091 ZPK=CHFO/PCAPLA/(PPSI+S)
      ZPKP=CHFO*(CSGF/ASGF+CVL/AVEL)+ZPK*(DRDU-SUM2+CLAMD*PPSI)
      ZPKP = CFP*ZPKP
      ZPK1=ZPK
      ZPK=DRDU*ZPK1
      GO TO 2000
 1092 IF(ICASE.EQ.9) GO TO 1093
      CKEF = 1./(1.-REACT)
```

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```
      GO TO 1094
 1093 CKEF = 1./(1.-REAC(M))
 1094 ZPK1 = CHFO/CKEF/PCAPLA/(PPSI+S)
      ZPK=ZPK1*DRDU
      ZPKP = CHFO*(CSGF/ASGF+CVL/AVEL-SUM2/(PCAPLA*S+SUM1)+
     1       CLAMD*SUM1/PCAPLA/(PCAPLA*S+SUM1))
      GO TO 2000
C
 1100 CONTINUE
C.................................................................
C  *  POINT KINETICS(NON-UNIFORM RADIAL)
C.................................................................
      DO 1150 I=1,IMAX
      JR=JMX(I)
      DO 1150 J=1,JR
      M=JJD(I,J)
      SUM1=CMPLX(0.,0.)
      SUM2=CMPLX(0.,0.)
C
      DO 1130 JJ=1,6
      SUM1=SUM1+PBET(M,JJ)*S/(S+PLAMDA(JJ))
      SUM2=SUM2+CBET(M,JJ)*S/(S+PLAMDA(JJ))
 1130 CONTINUE
C
      A=CXGF(M)/XSGF(M)+CXVL(M)/XVEL(M)
      B=CAL(M)-SUM2+CLAM(M)/GTIME(M)*SUM1
      AAA(M)=(A+B/(GTIME(M)*S+SUM1))*ASRC(I,J)*CHFO*CFP
 1150 CONTINUE
C
      GO TO 2000
 1199 CONTINUE
C
      IF(ICASE.EQ.6) GO TO 1500
C.................................................................
C  *  POINT KINETICS(NON-UNIFORM AXIAL)
C         ICASE = 3  :  NON-UNIFORM AXIAL
C         ICASE = 7  :  SPECIFIC CHANNEL
C.................................................................
      DO 1290 K=1,KMAX
      SUM1=CMPLX(0.,0.)
      SUM2=CMPLX(0.,0.)
C
      DO 1270 JJ=1,6
      SUM1=SUM1+PBET(K,JJ)*S/(S+PLAMDA(JJ))
      SUM2=SUM2+CBET(K,JJ)*S/(S+PLAMDA(JJ))
 1270 CONTINUE
C
      A=CXGF(K)/XSGF(K)+CXVL(K)/XVEL(K)
      B=CAL(K)-SUM2+CLAM(K)/GTIME(K)*SUM1
      IF(ICASE.EQ.3) AAA(K)=(A+B/(GTIME(K)*S+SUM1))*AXSRC(K)*CHFO*CFP
      IF(ICASE.EQ.7) AAA(K)=(A+B/(GTIME(K)*S+SUM1))*SRC(ISPEC,
     1               JSPEC,K)*CHFO*CFP
 1290 CONTINUE
C
      GO TO 2000
 1400 CONTINUE
C
C.................................................................
C  *  AXIALLY COUPLED KINETICS, IDENTICAL CHANNEL(1-D)
C.................................................................
```

```
      M=JJU(ISPEC,JSPEC)
C
      DO 1450 K=1,KMAX
      SUM1=CMPLX(0.,0.)
      SUM2=CMPLX(0.,0.)
C
      DO 1420 JJ=1,6
      JL=JJ+4
      SUM1=SUM1+S*SIG1(M,K,JL)/(S+PLAMDA(JJ))
      SUM2=SUM2+S*CSIG1(M,K,JL)/(S+PLAMDA(JJ))
 1420 CONTINUE
C
      XAIN=CMPLX(0.,0.)
      XAION=0.
      KM1=K-1
      KP1=K+1
C
      DO 1430 N=1,2
      XAIN=XAIN+GAMN(M,K,N)
      XAION=XAION+GAMON(M,K,N)
C
      IF(N.EQ.1) GO TO 1425
      IF(N.EQ.2) GO TO 1428
 1425 IF(K.EQ.1) ZNI(K,N)=CMPLX(0.,0.)
      IF(K.NE.1) ZNI(K,N)=CSIG1(M,KM1,2)/SIG1(M,KM1,2)*GANM(M,K,M)
      GO TO 1430
 1428 IF(K.EQ.KMAX) ZNI(K,N)=CMPLX(0.,0.)
      IF(K.NE.KMAX) ZNI(K,N)=CSIG1(M,KP1,2)/SIG1(M,KP1,2)*GANM(M,K,N)
 1430 CONTINUE
C
      BI(K)=(SIG1(M,K,1)+S/SIG1(M,K,4))/SIG1(M,K,2)+
     1       XAIN+(SUM1-1.)/XKEFF
      RKI(K)=((1.-SUM1)/XKEFF+BI(K))*CSIG1(M,K,2)/SIG1(M,K,2)-
     1      SUM2/XKEFF-XAION*CSIG1(M,K,3)/SIG1(M,K,3)-
     2      (CSIG1(M,K,1)-S*CSIG1(M,K,4)/SIG1(M,K,4)**2)/SIG1(M,K,2)
 1450 CONTINUE
C
      GO TO 2000
 1500 CONTINUE
C
C.................................................................
C  *  AXIALLY COUPLED KINETICS, AVERAGE CHANNEL(1-D)
C.................................................................
      DO 1560 K=1,KMAX
      SUM1=CMPLX(0.,0.)
      SUM2=CMPLX(0.,0.)
C
      DO 1520 JJ=1,6
      SUM1=SUM1+S*RDET(K,JJ)/(S+PLAMDA(JJ))
      SUM2=SUM2+S*RCBT(K,JJ)/(S+PLAMDA(JJ))
 1520 CONTINUE
C
      XAIN=CMPLX(0.,0.)
      XAION=0.
      KM1=K-1
      KP1=K+1
C
      DO 1530 N=1,2
      XAIN=XAIN+RAIN(K,N)
      XAION=XAION+RAION(K,N)
```

```
C
      IF(N.EQ.1) GO TO 1525
      IF(N.EQ.2) GO TO 1528
 1525 IF(K.EQ.1) ZNI(K,N)=CMPLX(0.,0.)
      IF(K.NE.1) ZNI(K,N)=ACXF(KM1)/AXF(KM1)*RANI(K,N)
      GO TO 1530
 1528 IF(K.EQ.KMAX) ZNI(K,N)=CMPLX(0.,0.)
      IF(K.NE.KMAX) ZNI(K,N)=ACXF(KP1)/AXF(KP1)*RANI(K,N)
 1530 CONTINUE
C
      BI(K)=(AXA(K)+S/AV(K))/AXF(K)+RAIR(K)+(SUM1-1.)/XKEFF+XAIN
      RKI(K)=((1.-SUM1)/XKEFF+BI(K))*ACXF(K)/AXF(K)-SUM2/XKEFF-
     1        (RAIOR(K)+XAION)*ACDF(K)/ADF(K)-
     2        (ACXA(K)-S*ACV(K)/AV(K)**2)/AXF(K)
 1560 CONTINUE
C
      GO TO 2000
 1600 CONTINUE
 1700 CONTINUE
C
C.....................................................................
C  *  GENERAL SPACE NODAL KINETICS(3-D)
C.....................................................................
      DO 1780 I=1,IMAX
      IM1=I-1
      IP1=I+1
      IF(I.GT.1) JIM1=JMX(IM1)
      JR=JMX(I)
      DO 1780 J=1,JR
      JM1=J-1
      JP1=J+1
      M=JJD(I,J)
      IF(I.NE.1) MIM1=JJD(IM1,J)
      IF(I.NE.IMAX) MIP1=JJD(IP1,J)
      IF(J.NE.1) MJM1=JJD(I,JM1)
      IF(J.NE.JR) MJP1=JJD(I,JP1)
C
      DO 1780 K=1,KMAX
      SUM1=CMPLX(0.,0.)
      SUM2=CMPLX(0.,0.)
C
      DO 1710 JJ=1,6
      JL=JJ+4
      SUM1=SUM1+S*SIG1(M,K,JL)/(S+PLAMDA(JJ))
      SUM2=SUM2+S*CSIG1(M,K,JL)/(S+PLAMDA(JJ))
 1710 CONTINUE
C
      XAIN=CMPLX(0.,0.)
      XAION=0.
      KM1=K-1
      KP1=K+1
C
      DO 1750 N=1,6
      XAIN=XAIN+GAMN(M,K,N)
      XAION=XAION+GAMON(M,K,N)
C
      IF(N.EQ.1) GO TO 1715
      IF(N.EQ.2) GO TO 1720
      IF(N.EQ.3) GO TO 1725
      IF(N.EQ.4) GO TO 1730
      IF(N.EQ.5) GO TO 1735
      IF(N.EQ.6) GO TO 1740
 1715 IF(I.EQ.1) GO TO 1717
      IF(J.GT.JIM1.AND.J.LE.JR) GO TO 1717
      XZNI(M,K,N)=CSIG1(MIM1,K,2)/SIG1(MIM1,K,2)*GANM(M,K,N)
      GO TO 1750
 1717 XZNI(M,K,N)=CSIG1(MIP1,K,2)/SIG1(MIP1,K,2)*GANM(M,K,N)
C1717 XZNI(M,K,N)=CMPLX(0.,0.)
      GO TO 1750
C1720 IF(J.EQ.1) XZNI(M,K,N)=CSIG1(M,K,2)/SIG1(M,K,2)*GANM(M,K,N)
 1720 IF(J.EQ.1) XZNI(M,K,N)=CSIG1(MJP1,K,2)/SIG1(MJP1,K,2)*GANM(M,K,N)
      IF(J.NE.1) XZNI(M,K,N)=CSIG1(MJM1,K,2)/SIG1(MJM1,K,2)*GANM(M,K,N)
      GO TO 1750
C1725 IF(I.EQ.IMAX) XZNI(M,K,N)=CSIG1(M,K,2)/SIG1(M,K,2)*GANM(M,K,N)
 1725 IF(I.EQ.IMAX) XZNI(M,K,N)=CSIG1(MIM1,K,2)/SIG1(MIM1,K,2)*
     1          GANM(M,K,N)
      IF(I.NE.IMAX) XZNI(M,K,N)=CSIG1(MIP1,K,2)/SIG1(MIP1,K,2)*
     1                    GANM(M,K,N)
      GO TO 1750
C1730 IF(J.EQ.JR) XZNI(M,K,N)=CMPLX(0.,0.)
 1730 IF(J.EQ.JR) XZNI(M,K,N)=CSIG1(MJM1,K,2)/SIG1(MJM1,K,2)*GANM(M,K,N)
      IF(J.NE.JR) XZNI(M,K,N)=CSIG1(MJP1,K,2)/SIG1(MJP1,K,2)*GANM(M,K,N)
      GO TO 1750
 1735 IF(K.EQ.1) XZNI(M,K,N)=CMPLX(0.,0.)
      IF(K.NE.1) XZNI(M,K,N)=CSIG1(M,KM1,2)/SIG1(M,KM1,2)*GANM(M,K,N)
      GO TO 1750
 1740 IF(K.EQ.KMAX) XZNI(M,K,N)=CMPLX(0.,0.)
      IF(K.NE.KMAX) XZNI(M,K,N)=CSIG1(M,KP1,2)/SIG1(M,KP1,2)*GANM(M,K,N)
 1750 CONTINUE
C
      XBM(M,K)=(SIG1(M,K,1)+S/SIG1(M,K,4))/SIG1(M,K,2)+
     1    XAIN+(SUM1-1.)/XKEFF
      XRKM(M,K)=((1.-SUM1)/XKEFF+XBM(M,K))*CSIG1(M,K,2)/SIG1(M,K,2)-
     1   SUM2/XKEFF-XAION*CSIG1(M,K,3)/SIG1(M,K,3)-
     2   (CSIG1(M,K,1)-S*CSIG1(M,K,4)/SIG1(M,K,4)**2)/SIG1(M,K,2)
 1780 CONTINUE
      GO TO 2000
 1785 CONTINUE
C
C...................................................................
C  *   ICASE = 13, 14, 15  TWO GROUP COUPLING
C...................................................................
      SSSUM=0.
      DO 1786 I=1,IMAX
      JR=JMX(I)
      DO 1786 J=1,JR
      M=JJD(I,J)
      DO 1786 K=1,KMAX
      SSSUM=SSSUM+SIG1(M,K,2)*TFLX(1,M,K)+SIG2(M,K,2)*TFLX(2,M,K)
 1786 CONTINUE
C
      AAAAA=FLOAT(KMAX)*FLOAT(IMAX)*FLOAT(JMAX)/SSSUM
      DO 1788 I=1,IMAX
      JR=JMX(I)
      DO 1788 J=1,JR
      M=JJD(I,J)
      DO 1788 K=1,KMAX
      XQI1=AAAAA*SIG1(M,K,2)*TFLX(1,M,K)
      XQI2=AAAAA*SIG2(M,K,2)*TFLX(2,M,K)
      TOTQI=XQI1+XQI2
      XMULT=SRC(I,J,K)/TOTQI
      XTFLX(1,M,K)=XQI1*XMULT
      XIFLX(2,M,K)=XQI2*XMULT
 1788 CONTINUE
C
      IF(ICASE.EQ.14) GO TO 1851
C
      AOV=ANT/VOL*2./DX
      BIJ01(1,1,1)=0.
      BIJ02(1,1,1)=0.
      DIJ01(1,1,1)=0.
      DIJ02(1,1,1)=0.
      DJOK1(1,1,1)=0.
      DJOK2(1,1,1)=0.
      TXFJ1(1,1,1)=1.
      TXFJ2(1,1,1)=1.
      TCXFJ1(1,1,1)=0.
      TCXFJ2(1,1,1)=0.
      DDC1(1,1,1)=0.
      DDC2(1,1,1)=0.
      DDOF1(1,1,1)=0.
      DDOF2(1,1,1)=0.
      TFLX1(1,1,1)=0.
      TFLXI(1,1,1)=0.
      N=KMAX
      BIJ01(1,N,2)=0.
      BIJ02(1,N,2)=0.
      DIJ01(1,N,2)=0.
      DIJ02(1,N,2)=0.
      DJOK1(1,N,2)=0.
      DJOK2(1,N,2)=0.
      TXFJ1(1,N,2)=1.
      TXFJ2(1,N,2)=1.
      TCXFJ1(1,N,2)=0.
      TCXFJ2(1,N,2)=0.
      DDC1(1,N,2)=0.
      DDC2(1,N,2)=0.
      DDOF1(1,N,2)=0.
      DDOF2(1,N,2)=0.
      TFLX1(1,N,2)=0.
      TFLXT(1,N,2)=0.
C
C
      DO 1830 I=1,IMAX
      JR=JMX(I)
      DO 1830 J=1,JR
      M=JJD(I,J)
      DO 1830 K=1,KMAX
      KM1=K-1
      KP1=K+1
      SUM1=CMPLX(0.,0.)
      SUM2=SUM1
C
      DO 1790 NN=1,6
      N=NN+4
      SUM1=SUM1+SIG1(M,K,N)*S/(S+PLAMDA(NN))
 1790 SUM2=SUM2+CSIG1(M,K,N)*S/(S+PLAMDA(NN))
C
C
      IF(K.EQ.1) GO TO 1792
```

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      BIJO1(M,K,1)=AOV*SIG1(M,K,3)*SIG1(M,KM1,3)/(SIG1(M,K,3)+
     1             SIG1(M,KM1,3))
      BIJO2(M,K,1)=AOV*SIG2(M,K,3)*SIG2(M,KM1,3)/(SIG2(M,K,3)+
     1             SIG2(M,KM1,3))
      DJOK1(M,K,1)=SIG1(M,KM1,3)
      DJOK2(M,K,1)=SIG2(M,KM1,3)
      DIJO1(M,K,1)=AOV/(SIG1(M,K,3)+SIG1(M,KM1,3))**2
      DIJO2(M,K,1)=AOV/(SIG2(M,K,3)+SIG2(M,KM1,3))**2
      DDOF1(M,K,1)=(DJOK1(M,K,1)**2)*DIJO1(M,K,1)/SIG1(M,KM1,2)
      DDOF2(M,K,1)=(DJOK2(M,K,1)**2)*DIJO2(M,K,1)/SIG2(M,KM1,2)
      DDC1(M,K,1)=(SIG1(M,K,3)**2)*DIJO1(M,K,1)*CSIG1(M,KM1,3)
      DDC2(M,K,1)=(SIG2(M,K,3)**2)*DIJO2(M,K,1)*CSIG2(M,KM1,3)
      TXFJ1(M,K,1)=SIG1(M,KM1,2)
      TXFJ2(M,K,1)=SIG2(M,KM1,2)
      TCXFJ1(M,K,1)=CSIG1(M,KM1,2)
      TCXFJ2(M,K,1)=CSIG1(M,KM1,2)
      TFLX1(M,K,1)=XTFLX(1,M,KM1)
      TFLXT(M,K,1)=SRC(I,J,KM1)
C
 1792 IF(K.EQ.KMAX) GO TO 1795
      BIJO1(M,K,2)=AOV*SIG1(M,K,3)*SIG1(M,KP1,3)/(SIG1(M,K,3)+
     1             SIG1(M,KP1,3))
      BIJO2(M,K,2)=AOV*SIG2(M,K,3)*SIG2(M,KP1,3)/(SIG2(M,K,3)+
     1             SIG2(M,KP1,3))
      DJOK1(M,K,2)=SIG1(M,KP1,3)
      DJOK2(M,K,2)=SIG2(M,KP1,3)
      DIJO1(M,K,2)=AOV/(SIG1(M,K,3)+SIG1(M,KP1,3))**2
      DIJO2(M,K,2)=AOV/(SIG2(M,K,3)+SIG2(M,KP1,3))**2
      DDOF1(M,K,2)=(DJOK1(M,K,2)**2)*DIJO1(M,K,2)/SIG1(M,KP1,2)
      DDOF2(M,K,2)=(DJOK2(M,K,2)**2)*DIJO2(M,K,2)/SIG2(M,KP1,2)
      DDC1(M,K,2)=(SIG1(M,K,3)**2)*DIJO1(M,K,2)*CSIG1(M,KP1,3)
      DDC2(M,K,2)=(SIG2(M,K,3)**2)*DIJO2(M,K,2)*CSIG2(M,KP1,3)
      TXFJ1(M,K,2)=SIG1(M,KP1,2)
      TXFJ2(M,K,2)=SIG2(M,KP1,2)
      TCXFJ1(M,K,2)=CSIG1(M,KP1,2)
      TCXFJ2(M,K,2)=CSIG1(M,KP1,2)
      TFLX1(M,K,2)=XTFLX(1,M,KP1)
      TFLXT(M,K,2)=SRC(I,J,KP1)
C
 1795 CONTINUE
C
      TXF1=SIG1(M,K,2)
      TXF2=SIG2(M,K,2)
      TEMP1=SIG1(M,K,1)+SIG1(M,K,11)+BIJO1(M,K,1)+BIJO1(M,K,2)
      TEMP2=SIG2(M,K,1)+BIJO2(M,K,1)+BIJO2(M,K,2)
      TGAM1=1./TXF1/SIG1(M,K,4)
      TGAM2=1./TXF2/SIG2(M,K,4)
      TCXF1=CSIG1(M,K,2)
      TCXF2=CSIG2(M,K,2)
      CDD1=CSIG1(M,K,3)*((DJOK1(M,K,1)**2)*DIJO1(M,K,1)+
     1     (DJOK1(M,K,2)**2)*DIJO1(M,K,2))
      CDD2=CSIG2(M,K,3)*((DJOK2(M,K,1)**2)*DIJO2(M,K,1)+
     1     (DJOK2(M,K,2)**2)*DIJO2(M,K,2))
C
C
      TBI1(M,K)=S*TGAM1+TEMP1/TXF1
      TF1(M,K)=(1.-SUM1)/XKEFF
      TKI1(M,K)=((TEMP1*TCXF1/TXF1-CSIG1(M,K,1)-CSIG1(M,K,11)-CDD1+
     1          S*(SIG1(M,K,4)*TCXF1+TXF1*CSIG1(M,K,4))*TGAM1**2)*
     2    XTFLX(1,M,K)/TXF1+CSIG1(M,K,3)*(DDOF1(M,K,1)*TFLX1(M,K,1)+
     3             DDOF1(M,K,2)*TFLX1(M,K,2))-SUM2*SRC(1,J,K)/XKEFF)*CHFO
C
      DO 1800 N=1,2
      TRIJ1(M,K,N)=(-DDC1(M,K,N)/TXF1*(XTFLX(1,M,K)-TFLX1(M,K,N))+
     1  BIJO1(M,K,N)*TCXFJ1(M,K,N)/(TXFJ1(M,K,N)**2)*TFLX1(M,K,N))*CHFO
      TRIJ2(M,K,N)=(DDC2(M,K,N)*((TFLXT(M,K,N)-TFLX1(M,K,N))/
     1  TXFJ2(M,K,N)-XTFLX(2,M,K)/TXF2)-BIJO2(M,K,N)*TCXFJ2(M,K,N)/
     2            (TXFJ2(M,K,N)**2)*(TFLXT(M,K,N)-TFLX1(M,K,N)))*CHFO
      TZN1(M,K,N)=BIJO1(M,K,N)/TXFJ1(M,K,N)
      TZN2(M,K,N)=BIJO2(M,K,N)/TXFJ2(M,K,N)
 1800 CONTINUE
C
      TGI(M,K)=-S*TGAM2-TEMP2/TXF2
      TBI2(M,K)=TGI(M,K)-SIG1(M,K,11)/TXF1
      TKI2(M,K)=((-(SIG2(M,K,4)*TCXF2+TXF2*CSIG2(M,K,4))*S*TGAM2**2+
     1             (CSIG2(M,K,1)-TCXF2/TXF2*TEMP2+CDD2)/TXF2)*
     2             (-XTFLX(2,M,K))+(CSIG1(M,K,11)-SIG1(M,K,11)*TCXF1/
     3             TXF1)*XTFLX(1,M,K)/TXF1+CSIG1(M,K,3)*(DDOF2(M,K,1)*
     4           (TFLXT(M,K,1)-TFLX1(M,K,1))+DDOF2(M,K,2)*(TFLXT(M,K,2)-
     5             TFLX1(M,K,2))))*CHFO
C
 1830 CONTINUE
C
C.................................................................
C *   MATRICES FORMATION, WW1, WW2, TZ1, TZ2, TWO, THREE
C.................................................................
      DO 1832 K=1,KMAX
      DO 1832 J=1,KMAX
      WW1(K,J)=CMPLX(0.,0.)
      WW2(K,J)=CMPLX(0.,0.)
      TZ1(K,J)=CMPLX(0.,0.)
      TZ2(K,J)=CMPLX(0.,0.)
      TWO(K,J)=CMPLX(0.,0.)
      THREE(K,J)=CMPLX(0.,0.)
 1832 CONTINUE
C
C
      DO 1850 K=1,KMAX
      KM1=K-1
      KP1=K+1
      DO 1850 J=1,KMAX
      IF(J.NE.K) GO TO 1835
      WW1(K,J)=TBI1(1,K)
      WW2(K,J)=TBI2(1,K)
      TZ1(K,J)=TKI1(1,K)
      TZ2(K,J)=TKI2(1,K)
      TWO(K,J)=TFI(1,K)
      THREE(K,J)=TGI(1,K)
      GO TO 1850
C
 1835 CONTINUE
C
      IF(J.EQ.KM1.OR.J.EQ.KP1) GO TO 1840
      GO TO 1850
 1840 CONTINUE
      IF(K.EQ.1) GO TO 1842
      WW1(K,KM1)=-TZN1(1,K,1)
      WW2(K,KM1)=TZN2(1,K,1)
      TZ1(K,KM1)=TRIJ1(1,K,1)
      TZ2(K,KM1)=TRIJ2(1,K,1)
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      THREE(K,KM1)=TZN2(1,K,1)
 1842 IF(K.EQ.KMAX) GO TO 1850
      WW1(K,KP1)=-TZN1(1,K,2)
      WW2(K,KP1)=TZN2(1,K,2)
      TZ1(K,KP1)=TRIJ1(1,K,2)
      TZ2(K,KP1)=TRIJ2(1,K,2)
      THREE(K,KP1)=TZN2(1,K,2)
 1850 CONTINUE
      GO TO 2000
 1851 CONTINUE
C......................................................................
C   *  ICASE = 14, TWO GROUP CHECKER BOARD, 2-D
C......................................................................
      AOV=ANR/VOL*2./DZ
      DO 1856 I=1,IMAX
      JR=JMX(I)
      DO 1856 J=1,JR
      M=JJD(I,J)
      SUM1A=0.
      SUM1F=0.
      SUM2A=0.
      SUM2F=0.
      SUM1D=0.
      SUM1V=0.
      SUM2D=0.
      SUM2V=0.
      SUM1R=0.
      SUMSC=0.
      SUM1CA=0.
      SUM1CF=0.
      SUM2CA=0.
      SUM2CF=0.
      SUM1CD=0.
      SUM1CV=0.
      SUM2CD=0.
      SUM2CV=0.
      SUM1CR=0.
      SUMTF1=0.
      SUMTF2=0.
      SUMFX1=0.
      SUMFX2=0.
C
      DO 1852 JJ=1,6
      SUMBT(JJ)=0.
      SUMCB1(JJ)=0.
 1852 SUMCB2(JJ)=0.
C
      DO 1854 K=1,KMAX
      TFF1=XTFLX(1,M,K)
      TFF2=XTFLX(2,M,K)
      SUMFX1=SUMFX1+TFF1
      SUMFX2=SUMFX2+TFF2
      SUM1A=SUM1A+SIG1(M,K,1)*TFF1
      SUM1F=SUM1F+SIG1(M,K,2)*TFF1
      SUM1D=SUM1D+SIG1(M,K,3)*TFF1
      SUM1V=SUM1V+SIG1(M,K,4)*TFF1
      SUM1R=SUM1R+SIG1(M,K,11)*TFF1
      SUM2A=SUM2A+SIG2(M,K,1)*TFF2
      SUM2F=SUM2F+SIG2(M,K,2)*TFF2
      SUM2D=SUM2D+SIG2(M,K,3)*TFF2
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      SUM2V=SUM2V+SIG2(M,K,4)*TFF2
      SUM1CA=SUM1CA+CSIG1(M,K,1)*TFF1
      SUM1CF=SUM1CF+CSIG1(M,K,2)*TFF1
      SUM1CD=SUM1CD+CSIG1(M,K,3)*TFF1
      SUM1CV=SUM1CV+CSIG1(M,K,4)*TFF1
      SUM1CR=SUM1CR+CSIG1(M,K,11)*TFF1
      SUM2CA=SUM2CA+CSIG2(M,K,1)*TFF2
      SUM2CF=SUM2CF+CSIG2(M,K,2)*TFF2
      SUM2CD=SUM2CD+CSIG2(M,K,3)*TFF2
      SUM2CV=SUM2CV+CSIG2(M,K,4)*TFF2
C
      DO 1853 JJ=1,6
      JJJ=JJ+4
      SUMBT(JJ)=SUMBT(JJ)+SIG1(M,K,JJJ)*(SIG1(M,K,2)*TFF1+
     1          SIG2(M,K,2)*TFF2)
      SUMCB1(JJ)=SUMCB1(JJ)+CSIG1(M,K,JJJ)*(SIG1(M,K,2)*TFF1+
     1           SIG2(M,K,2)*TFF2)
 1853 SUMCB2(JJ)=SUMCB2(JJ)+CSIG1(M,K,2)*TFF1+CSIG2(M,K,2)*TFF2
C
      SUMTF1=SUMTF1+TFF1
      SUMTF2=SUMTF2+TFF2
      SUMSC=SUMSC+SIG1(M,K,2)*TFF1+SIG2(M,K,2)*TFF2
 1854 CONTINUE
C
      ATFLX(M,1)=SUMFX1/FLOAT(KMAX)
      ATFLX(M,2)=SUMFX2/FLOAT(KMAX)
      XXA(M,1)=SUM1A/SUMTF1
      XXF(M,1)=SUM1F/SUMTF1
      XXD(M,1)=SUM1D/SUMTF1
      XXV(M,1)=SUM1V/SUMTF1
      XXR(M,1)=SUM1R/SUMTF1
      XXA(M,2)=SUM2A/SUMTF2
      XXF(M,2)=SUM2F/SUMTF2
      XXD(M,2)=SUM2D/SUMTF2
      XXV(M,2)=SUM2V/SUMTF2
      CXXA(M,1)=SUM1CA/SUMTF1
      CXXF(M,1)=SUM1CF/SUMTF1
      CXXD(M,1)=SUM1CD/SUMTF1
      CXXV(M,1)=SUM1CV/SUMTF1
      CXXR(M,1)=SUM1CR/SUMTF1
      CXXA(M,2)=SUM2CA/SUMTF2
      CXXF(M,2)=SUM2CF/SUMTF2
      CXXD(M,2)=SUM2CD/SUMTF2
      CXXV(M,2)=SUM2CV/SUMTF2
C
      DO 1855 JJ=1,6
      PBET(M,JJ)=SUMBT(JJ)/SUMSC
 1855 CBET(M,JJ)=(SUMCB1(JJ)-PBET(M,JJ)*SUMCB2(JJ))/SUMSC
 1856 CONTINUE
C
      DO 1880 I=1,IMAX
      JR=JMX(I)
      IF(I.EQ.1) IPR=2
      IF(I.EQ.2) IPR=1
      DO 1880 J=1,JR
      IF(J.EQ.1) JPR=2
      IF(J.EQ.2) JPR=1
      SUM1=CMPLX(0.,0.)
      SUM2=SUM1
      M=JJD(I,J)
      MIPR=JJD(IPR,J)
      MJPR=JJD(I,JPR)
      BIJ01(M,1,1)=AOV*XXD(M,1)*XXD(MIPR,1)/(XXD(M,1)+XXD(MIPR,1))
      BIJ02(M,1,1)=AOV*XXD(M,2)*XXD(MIPR,2)/(XXD(M,2)+XXD(MIPR,2))
      BIJ01(M,1,2)=AOV*XXD(M,1)*XXD(MJPR,1)/(XXD(M,1)+XXD(MJPR,1))
      BIJ02(M,1,2)=AOV*XXD(M,2)*XXD(MJPR,2)/(XXD(M,2)+XXD(MJPR,2))
      DJOK1(M,1,1)=XXD(MIPR,1)
      DJOK2(M,1,1)=XXD(MIPR,2)
      DJOK1(M,1,2)=XXD(MJPR,1)
      DJOK2(M,1,2)=XXD(MJPR,2)
      DIJ01(M,1,1)=AOV/(XXD(M,1)+XXD(MIPR,1))**2
      DIJ02(M,1,1)=AOV/(XXD(M,2)+XXD(MIPR,2))**2
      DIJ01(M,1,2)=AOV/(XXD(M,1)+XXD(MJPR,1))**2
      DIJ02(M,1,2)=AOV/(XXD(M,2)+XXD(MJPR,2))**2
      DDOF1(M,1,1)=(DJOK1(M,1,1)**2)*DIJ01(M,1,1)/XXF(MIPR,1)
      DDOF2(M,1,1)=(DJOK2(M,1,1)**2)*DIJ02(M,1,1)/XXF(MIPR,2)
      DDOF1(M,1,2)=(DJOK1(M,1,2)**2)*DIJ01(M,1,2)/XXF(MJPR,1)
      DDOF2(M,1,2)=(DJOK2(M,1,2)**2)*DIJ02(M,1,2)/XXF(MJPR,2)
      DDC1(M,1,1)=(XXD(M,1)**2)*DIJ01(M,1,1)*CXXD(MIPR,1)
      DDC2(M,1,1)=(XXD(M,2)**2)*DIJ02(M,1,1)*CXXD(MIPR,2)
      DDC1(M,1,2)=(XXD(M,1)**2)*DIJ01(M,1,2)*CXXD(MJPR,1)
      DDC2(M,1,2)=(XXD(M,2)**2)*DIJ02(M,1,2)*CXXD(MJPR,2)
      TXFJ1(M,1,1)=XXF(MIPR,1)
      TXFJ2(M,1,1)=XXF(MIPR,2)
      TXFJ1(M,1,2)=XXF(MJPR,1)
      TXFJ2(M,1,2)=XXF(MJPR,2)
      TCXFJ1(M,1,1)=CXXF(MIPR,1)
      TCXFJ2(M,1,1)=CXXF(MIPR,2)
      TCXFJ1(M,1,2)=CXXF(MJPR,1)
      TCXFJ2(M,1,2)=CXXF(MJPR,2)
      TFLX1(M,1,1)=ATFLX(MIPR,1)
      TFLX1(M,1,2)=ATFLX(MJPR,1)
      TFLXI(M,1,1)=ASRC(IPR,J)
      TFLXI(M,1,2)=ASRC(I,JPR)
      TXF1=XXF(M,1)
      TXF2=XXF(M,2)
      TEMP1=XXA(M,1)+XXR(M,1)+2.*(BIJ01(M,1,1)+BIJ01(M,1,2))
      TEMP2=XXA(M,2)+2.*(BIJ02(M,1,1)+BIJ02(M,1,2))
      TGAM1=1./TXF1/XXV(M,1)
      TGAM2=1./TXF2/XXV(M,2)
      TCXF1=CXXF(M,1)
      TCXF2=CXXF(M,2)
      CDD1=CXXD(M,1)*2.*((DJOK1(M,1,1)**2)*DIJ01(M,1,1)+
     1      (DJOK1(M,1,2)**2)*DIJ01(M,1,2))
      CDD2=CXXD(M,2)*2.*((DJOK2(M,1,1)**2)*DIJ02(M,1,1)+
     1      (DJOK2(M,1,2)**2)*DIJ02(M,1,2))
C
      DO 1870 JJ=1,6
      SUM1=SUM1+S*PBET(M,JJ)/(S+PLAMDA(JJ))
 1870 SUM2=SUM2+S*CBET(M,JJ)/(S+PLAMDA(JJ))
C
C
      TBI1(M,1)=S*TGAM1+TEMP1/TXF1
      TF1(M,1)=(1.-SUM1)/XKEFF
      TKI1(M,1)=((TEMP1*TCXF1/TXF1-CXXA(M,1)-CXXR(M,1)-CDD1+
     1          S*(XXV(M,1)*TCXF1+TXF1*CXXV(M,1))*TGAM1**2)*
     2    ATFLX(M,1)/TXF1+CXXD(M,1)*2.*(DDOF1(M,1,1)*TFLX1(M,1,1)+
     3          DDOF1(M,1,2)*TFLXI(M,1,2))-SUM2*ASRC(I,J)/XKEFF)*CHFO
C
      DO 1872 N=1,2
```

404

```
      TRIJ1(M,1,N)=(-DDC1(M,1,N)/TXF1*(ATFLX(M,1)-TFLX1(M,1,N))+
     1  BIJ01(M,1,N)*TCXFJ1(M,1,N)/(TXFJ1(M,1,N)**2)*TFLX1(M,1,N))*CHFO
      TRIJ2(M,1,N)=(DDC2(M,1,N)*((TFLXT(M,1,N)-TFLX1(M,1,N))/
     1  TXFJ2(M,1,N)-ATFLX(M,2)/TXF2)-BIJ02(M,1,N)*TCXFJ2(M,1,N)/
     2          (TXFJ2(M,1,N)**2)*(TFLXT(M,1,N)-TFLX1(M,1,N)))*CHFO
      TZN1(M,1,N)=BIJ01(M,1,N)/TXFJ1(M,1,N)
      TZN2(M,1,N)=BIJ02(M,1,N)/TXFJ2(M,1,N)
 1872 CONTINUE
C
      TG1(M,1)=-S*TGAM2-TEMP2/TXF2
      TB12(M,1)=TG1(M,1)-XXR(M,1)/TXF1
      TK12(M,1)=((-(XXV(M,2)*TCXF2+TXF2*CXXV(M,2))*S*TGAM2**2+
     1         (CXXA(M,2)-TCXF2/TXF2*TEMP2+CDD2)/TXF2)*
     2         (-ATFLX(M,2))+(CXXR(M,1)-XXR(M,1)*TCXF1/
     3         TXF1)*ATFLX(M,1)/TXF1+CXXD(M,1)*2.*(DDOF2(M,1,1)*
     4        (TFLXT(M,1,1)-TFLX1(M,1,1))+DDOF2(M,1,2)*(TFLXT(M,1,2)-
     5         TFLX1(M,1,2))))*CHFO
C
 1880 CONTINUE
C
C
      DO 1890 K=1,4
      DO 1890 J=1,4
      WW1(J,K)=CMPLX(0.,0.)
      WW2(J,K)=CMPLX(0.,0.)
      TZ1(J,K)=CMPLX(0.,0.)
      TZ2(J,K)=CMPLX(0.,0.)
      TWO(J,K)=CMPLX(0.,0.)
      THREE(J,K)=CMPLX(0.,0.)
 1890 CONTINUE
C
      DO 1895 K=1,4
      DO 1895 J=1,4
      IF(J.NE.K) GO TO 1895
      WW1(K,J)=TB11(K,1)
      WW2(K,J)=TB12(K,1)
      TZ1(K,J)=TK11(K,1)
      TZ2(K,J)=TK12(K,1)
      TWO(K,J)=TF1(K,1)
      THREE(K,J)=TG1(K,1)
 1895 CONTINUE
C
      WW1(1,2)=-2.*TZN1(1,1,2)
      WW2(1,2)=2.*TZN2(1,1,2)
      TZ1(1,2)=2.*TRIJ1(1,1,2)
      TZ2(1,2)=2.*TRIJ2(1,1,2)
      THREE(1,2)=2.*TZN2(1,1,2)
C
      WW1(1,3)=-2.*TZN1(1,1,1)
      WW2(1,3)=2.*TZN2(1,1,1)
      TZ1(1,3)=2.*TRIJ1(1,1,1)
      TZ2(1,3)=2.*TRIJ2(1,1,1)
      THREE(1,3)=2.*TZN2(1,1,1)
C
      WW1(2,1)=-2.*TZN1(2,1,2)
      WW2(2,1)=2.*TZN2(2,1,2)
      TZ1(2,1)=2.*TRIJ1(2,1,2)
      TZ2(2,1)=2.*TRIJ2(2,1,2)
      THREE(1,2)=2.*TZN2(2,1,2)
C
```

```
      WW1(2,4)=-2.*TZN1(2,1,1)
      WW2(2,4)=2.*TZN2(2,1,1)
      TZ1(2,4)=2.*TRIJ1(2,1,1)
      TZ2(2,4)=2.*TRIJ2(2,1,1)
      THREE(2,4)=2.*TZN2(2,1,1)
C
      WW1(3,1)=-2.*TZN1(3,1,1)
      WW2(3,1)=2.*TZN2(3,1,1)
      TZ1(3,1)=2.*TRIJ1(3,1,1)
      TZ2(3,1)=2.*TRIJ2(3,1,1)
      THREE(3,1)=2.*TZN2(3,1,1)
C
      WW1(3,4)=-2.*TZN1(3,1,2)
      WW2(3,4)=2.*TZN2(3,1,2)
      TZ1(3,4)=2.*TRIJ1(3,1,2)
      TZ2(3,4)=2.*TRIJ2(3,1,2)
      THREE(3,4)=2.*TZN2(3,1,2)
C
      WW1(4,2)=-2.*TZN1(4,1,1)
      WW2(4,2)=2.*TZN2(4,1,1)
      TZ1(4,2)=2.*TRIJ1(4,1,1)
      TZ2(4,2)=2.*TRIJ2(4,1,1)
      THREE(4,2)=2.*TZN2(4,1,1)
C
      WW1(4,3)=-2.*TZN1(4,1,2)
      WW2(4,3)=2.*TZN2(4,1,2)
      TZ1(4,3)=2.*TRIJ1(4,1,2)
      TZ2(4,3)=2.*TRIJ2(4,1,2)
      THREE(4,3)=2.*TZN2(4,1,2)
C
C
 2009 CONTINUE
C
      RETURN
      END
C
C
C*****************************************************************
      SUBROUTINE OPEN1(S,RATIO,NCH1,ICOUNT,KMAX4)
C*****************************************************************
C
C  ***  CALCULATE OPEN-LOOP TRANSFER FUNCTION  ***
C  ***  S = FREQUENCY
C  ***  RATIO = OPEN-LOOP TRANSFER FUNCTION
C
C
      COMPLEX S,RATIO,DD(30,30),FINV(30,30),DUMMY(30,30),
     1        FF(30,30),XL(30,30),F11(30,30),A(30,30)
      COMPLEX FALF,RAN1,GANM,ZN1,B1,RK1,XZN1,XBM,XRKM,F1
      COMPLEX THEOT,APIP(15,200),XUM(15),XUML, TGAM1,TPI1,
     1        ZL(200,5),AX(200,5),DENO,DENO1,YYZ,Y4,AI1,AIP1,AIP2,
     2        AIP4,FG(100),CFP
      COMPLEX DQ(200),TQ,YP(200),Y(200),AP(30)
      COMPLEX WW1,WW2,TZ1,TZ2,TWO,THREE,WAX,WZL
      COMPLEX XK,XKP,XKRA,XKPRA,RATIOP,RATIOW,
     @    RATIOK,OPTK,OPTH,OPTJ,OPOJ,TK(1000),PTK(1000),
     @    PTKI(1000),QP(30),XKC(200,5),WL(16),
     @    WKC(16),WKP(4),WKR,WKPR,WKRI,DUM3D(200),
     @    WWW,XXX,YYY,ZZZ,FFF,SUM1,SUMA,SUMB
      DIMENSION WKPR(200)
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      DIMENSION XXX(10000),YYY(10000),ZZZ(10000),WWW(10000),
     @          FFF(10000)
      COMMON/SKIN/XK(5,30,5,30),XKP(5,30),XKRA(10,10),XKPRA(10)
      COMMON/GKIN/IKIN,IDCHTY(15,15),ITY(225),JJMX(15),JJDB(15,15),
     @          ITYB(150)
      COMMON/TF/RATIOP,RATIOK,OPTK,OPTH,RATIOW,OPTJ,PTOJ
      COMMON/SIM1/IMAX,JMAX,KMAX,ICASE,ISPEC,JSPEC,INUCLR,XKEFF
      COMMON/SIM2/JMX(20),NFT(15,15,30),AL(15,15),TAL(15,15),
     1          BAL(15,15),ASRC(15,15),SRC(15,15,30),AEXP(15,15),
     2          REXP(15,15,30),AXSRC(30),XXSRC(30)
      COMMON/SIM3/JJD(15,15),DZ1(200),DZ2(200),NF(200,30),NB(200),
     1          SC(200,30,6),XEXP(200,30),SIG1(200,30,11),
     2          CSIG1(200,30,11)
      COMMON/KIN2/RDF(15,15),RCDF(15,15),RANOI(200,4),ADF(30),
     1          ACDF(30),GANOM(200,30,6),CFP
      COMMON/KIN3/RANI(200,4),GANM(200,30,6),ZNI(200,4),BI(200)
      COMMON/KIN5/RKI(200),XZNI(200,30,6),XBM(200,30),XRKM(200,30)
      COMMON/CONS12/ P,VCH,VIN(200),AXS(200),DH(200),DHIN(200),
     1     PH(200),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2     DENSF,VFG1,RHOG,G0(200),G02(200),H0(200),GC,G1,KLOSS(30),
     3     FRICMO(200),VGJH(200,30),COH(200,30),CZERO,VGJ,DPTS,
     4     G02RF(200),HFG1,ZSP(30),NUMBSP(200,30),ALHEAT,CXF(200),
     5     AVEQ,CHOMO1,CHOMO2,XKIN(200),XKEXI1(200)
      COMMON/CONSS1/ QDIS(200,30),Q0(200,30),DZ(200,30),Z(200,30),
     1     K1(200,30),CKIN(200,30),ZETA(200,30),D0IN(200,30),
     2     D0OUT(200,30),ALPIN(200,30), BEE(200,30),CP11(200,30),
     3     COR2PH(200,30), ZETSP(200,30), WIN
      COMMON/VOIDPT/FALF(200,30),F1(200), IGAM1(200),TP11(200)
      COMMON/TWOG2/WAX(100,100),WZL(100,100),TZ1(100,100),
     1          TZ2(100,100),TWO(100,100),THREE(100,100)
      COMMON/VSOS/VOL
      EQUIVALENCE (XXX(1),WAX(1,1)),(YYY(1),WZL(1,1)),
     @          (ZZZ(1),TZ1(1,1)),(WWW(1),TZ2(1,1)),
     @          (FFF(1),TWO(1,1))
C
C
      IOCASE=ICASE
      KKMAX=KMAX
      IF(ICASE.EQ.14) KKMAX=4
      MM=KKMAX+1
      TQ=CMPLX(0.,0.)
      IF(ICASE.EQ.10) GO TO 300
      IF(ICASE.EQ.13.OR.ICASE.EQ.14.OR.ICASE.EQ.15) GO TO 1500
      IF(ICASE.EQ.5) M=JJD(ISPEC,JSPEC)
      IF(ICASE.EQ.6) M=1
C
      DO 30 K=1,KMAX
      MY=ITY(M)
      F11(K,1)=FALF(MY,K)
      A(1,K)=1./FLOAT(KMAX)
      DO 30 J=1,KMAX
      FF(J,K)=CMPLX(0.,0.)
      XL(J,K)=CMPLX(0.,0.)
   30 CONTINUE
C
      DO 60 K=1,KMAX
      FF(K,K)=BI(K)
      KM1=K-1
      KP1=K+1
      IF(K.EQ.1) GO TO 35
      IF(K.EQ.KMAX) GO TO 40
      IF(ICASE.EQ.6) GO TO 33
      FF(K,KM1)=-GANM(M,K,1)
      FF(K,KP1)=-GANM(M,K,2)
      XL(K,K)=(RKI(K)*SRC(ISPEC,JSPEC,K)+CSIG1(M,K,3)/SIG1(M,K,3)*
     1        (GANOM(M,K,1)*SRC(ISPEC,JSPEC,KM1)+
     2        GANOM(M,K,2)*SRC(ISPEC,JSPEC,KP1)))*AVEQ
      XL(K,KM1)=-ZNI(K,1)*SRC(ISPEC,JSPEC,KM1)*AVEQ
      XL(K,KP1)=-ZNI(K,2)*SRC(ISPEC,JSPEC,KP1)*AVEQ
      GO TO 60
   33 FF(K,KM1)=-RANI(K,1)
      FF(K,KP1)=-RANI(K,2)
      XL(K,K)=(RKI(K)*AXSRC(K)+ACDF(K)/ADF(K)*
     1        (RANOI(K,1)*AXSRC(KM1)+RANOI(K,2)*AXSRC(KP1)))*
     2        AVEQ
      XL(K,KM1)=-ZNI(K,1)*AXSRC(KM1)*AVEQ
      XL(K,KP1)=-ZNI(K,2)*AXSRC(KP1)*AVEQ
      GO TO 60
   35 CONTINUE
      IF(ICASE.EQ.6) GO TO 38
      FF(K,KP1)=-GANM(M,K,2)
      XL(K,K)=(RKI(K)*SRC(ISPEC,JSPEC,K)+CSIG1(M,K,3)/SIG1(M,K,3)*
     1        GANOM(M,K,2)*SRC(ISPEC,JSPEC,KP1))*AVEQ
      XL(K,KP1)=-ZNI(K,2)*SRC(ISPEC,JSPEC,KP1)*AVEQ
      GO TO 60
   38 FF(K,KP1)=-RANI(K,2)
      XL(K,K)=(RKI(K)*AXSRC(K)+ACDF(K)/ADF(K)*
     1        RANOI(K,2)*AXSRC(KP1))*AVEQ
      XL(K,KP1)=-ZNI(K,2)*AXSRC(KP1)*AVEQ
      GO TO 60
   40 CONTINUE
      IF(ICASE.EQ.6) GO TO 50
      FF(K,KM1)=-GANM(M,K,1)
      XL(K,K)=(RKI(K)*SRC(ISPEC,JSPEC,K)+CSIG1(M,K,3)/SIG1(M,K,3)*
     1        GANOM(M,K,1)*SRC(ISPEC,JSPEC,KM1))*AVEQ
      XL(K,KM1)=-ZNI(K,1)*SRC(ISPEC,JSPEC,KM1)*AVEQ
      GO TO 60
   50 FF(K,KM1)=-RANI(K,1)
      XL(K,K)=(RKI(K)*AXSRC(K)+ACDF(K)/ADF(K)*
     1        RANOI(K,1)*AXSRC(KM1))*AVEQ
      XL(K,KM1)=-ZNI(K,1)*AXSRC(KM1)*AVEQ
   60 CONTINUE
      DO 61 K=1,KMAX
      DO 61 J=1,KMAX
      XL(K,J) = CFP*XL(K,J)
   61 CONTINUE
      IY=IIY(M)
      DO 62 K=1,KMAX
      AP(K)=XKP(IY,K)
      ZZZ(K)=QDIS(IY,K)/AVEQ
      DO 62 K1X=1,KMAX
      DO 62 K2=1,KMAX
      K12=(K2-1)*KMAX+K1X
      TK(K12)=XK(IY,K1X,IY,K2)
   62 WWW(K12)=XL(K1X,K2)
      CALL PMXMUL(KMAX,KMAX,KMAX,KMAX,WWW,TK,DUMMY,PTK,FFF,0)
      DO 63 K=1,KMAX
      DO 63 J=1,KMAX
      KJ=(J-1)*KMAX+K
   63 PTK(KJ)=FF(K,J)-PTK(KJ)
```

```
      MKM=KMAX*(KMAX+2)
      CALL PMXIV(KMAX,MKM,PTK,PTKI,XXX,YYY)
      CALL PMXMUI(KMAX,KMAX,KMAX,1,PTKI,WWW,AP,QP,FFF,1)
      SUM1=CMPLX(0.,0.)
      DO 64 K=1,KMAX
   64 SUM1=SUM1+QP(K)/FLOAT(KMAX)
      RATIOP=SUM1/AVEQ*VOL
C
C CALCULATE CLOSED-LOOP TRANSFER FUNCTION FOR DELK
C
      CALL PMXMUL(KMAX,KMAX,KMAX,KMAX,PTKI,WWW,TK,XXX,FFF,1)
C
C CALCULATE XXX*QDIS
C
      CALL PMXMUL(KMAX,KMAX,1,1,XXX,ZZZ,DUMMY,QP,FFF,0)
C
C CALCULATE AVERAGE RESPONSE
C
      SUMB=CMPLX(0.,0.)
      DO 46 K=1,KMAX
   46 SUMB=SUMB+QP(K)/(QP(K)+ZZZ(K))/FLOAT(KMAX)
      TQ=SUMB
C
C
      GO TO 2000
  300 CONTINUE
C
C.................................................................
C    *****      ICASE = 10,  RADIAL COUPLING(2-D)      *****
C    *****         CHECKER BOARD PROBLEM ONLY          *****
C.................................................................
C
      DO 320 I=1,2
      IPR=I+1
      IPRS=ISPEC+I
      JR=JMX(I)
      IF(I.EQ.2) IPR=I-1
      IF(I .EQ. 2)IPRS=ISPEC+I-2
      DO 320 J=1,2
      JPR=J+1
      JPRS=J+JSPEC
      IF(J.EQ.2) JPRS=JSPEC+J-2
      IS=ISPEC+I-1
      JS=JSPEC+J-1
      M=JJD(IS,JS)
      IT=IDCHTY(IS,JS)
      ITUD=IDCHTY(IPRS,JS)
      ITRL=IDCHTY(IS,JPRS)
      MX=1+2*(I-1)+(J-1)
      AX(MX,MX)=BI(M)
      XKC(MX,MX)=XKRA(IT,IT)
      WKP(MX)=XKPRA(IT)
      SUMQ=0.
      DO 325 K=1,KMAX
  325 SUMQ=SUMQ+QDIS(IT,K)
      ZZZ(MX)=SUMQ/KMAX/AVEQ
C
      ANOMQ=(RANOI(M,1)+RANOI(M,3))*ASRC(IPRS,JS)+(RANOI(M,2)+
     1        RANOI(M,4))*ASRC(IS,JPRS)
      ZI(MX,MX)=(RKI(M)*ASRC(IS,JS)+RCDF(IS,JS)/RDF(IS,JS)
     @            *ANOMQ)*AVEQ
C
      DO 310 MM=1,4
      IF(MM.EQ.MX) GO TO 310
      MPMM=MX+MM
      IF(MPMM.EQ.3.OR.MPMM.EQ.7) GO TO 305
      IF(MPMM.EQ.5) GO TO 308
      XKC(MX,MM)=XKRA(ITUD,ITUD)
      AX(MX,MM)=-RANI(M,1)-RANI(M,3)
      ZL(MX,MM)=(-ZNI(M,1)-ZNI(M,3))*ASRC(IPRS,JS)
      GO TO 310
  305 AX(MX,MM)=-RANI(M,2)-RANI(M,4)
      ZL(MX,MM)=(-ZNI(M,2)-ZNI(M,4))*ASRC(IS,JPRS)
      XKC(MX,MM)=XKRA(ITRL,ITRL)
      GO TO 310
  308 AX(MX,MM)=CMPLX(0.,0.)
      ZL(MX,MM)=CMPLX(0.,0.)
      XKC(MX,MM)=CMPLX(0.,0.)
  310 CONTINUE
      DO 311 MM=1,4
      ZL(MX,MM) = CFP*ZL(MX,MM)
  311 CONTINUE
C
      Y(MX)=ZL(MX,1)*F1(ITRL)+ZL(MX,2)*F1(ITUD)+
     @      ZL(MX,3)*F1(ITRL)+ZL(MX,4)*F1(ITUD)
  320 CONTINUE
      M=1
      DO 323 I=1,4
      IM=I+M-1
      DO 323 J=1,4
      JM=J+M-1    .
      IJ=(J-1)*4+I
      WL(IJ)=ZL(IM,JM)
      WKC(IJ)=XKC(IM,JM)
  323 CONTINUE
      CALL PMXMUL(4,4,4,4,WL,WKC,DUMMY,TK,FFF,0)
      DO 321 I=1,4
      IM=I+M-1
      DO 321 J=1,4
      JM=J+M-1
      IJ=(J-1)*4+I
  321 PTK(IJ)=AX(IM,JK)-TK(IJ)
      CALL PMXIV(4,24,PTK,PTKI,XXX,YYY)
      CALL PMXMUL(4,4,4,1,PTKI,WL,WKP,QP,FFF,1)
      SUM1=CMPLX(0.,0.)
      DO 322 I=1,4
  322 SUM1=SUM1+QP(I)/4.
      RATIOP=SUM1/AVEQ*VOL
      CALL PMXMUL(4,4,4,4,PTKI,WL,WKC,XXX,FFF,1)
      CALL PMXMUL(4,4,1,1,XXX,ZZZ,DUMMY,QP,FFF,0)
      SUMB=CMPLX(0.,0.)
      DO 56 I=1,4
      SUMB=SUMB+QP(I)/(QP(I)+ZZZ(I))/4./VOL
   56 CONTINUE
      TQ=SUMB
C
C
      GO TO 2000
 1500 CONTINUE
C.....................................................................
```

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C  *    TWO GROUP AXIAL COUPLING (ICASE = 13): MATRIX OPERATION
C.....................................................................
      M=JJD(ISPEC,JSPEC)
      K=KKMAX
      CALL MATXIN(K,MM,FINV,WW1,ICOUNT)
      CALL MATMUL(K,K,K,K,WW2,FINV,TWO,DD,1,ICOUNT)
      CALL MATMUL(K,K,K,K,WW2,FINV,TZ1,DUMMY,1,ICOUNT)
C
      DO 1520 I=1,KKMAX
      IF(ICASE.EQ.14) F11(I,1)=F1(I)
      MY=ITY(M)
      IF(ICASE.EQ.13) F11(I,1)=FALF(MY,I)
      A(I,I)=1./FLOAT(KKMAX)
      DO 1520 J=1,KKMAX
      FF(I,J)=DD(I,J)-THREE(I,J)
 1520 XL(I,J)=TZ2(I,J)-DUMMY(I,J)
      IY=ITY(M)
      DO 1562 K=1,KMAX
      AP(K)=XKP(IY,K)
      ZZZ(K)=QDIS(IY,K)/AVEQ
      DO 1562 K1X=1,KMAX
      DO 1562 K2=1.KMAX
      K12=(K2-1)*KMAX+K1X
      TK(K12)=XK(IY,K1X,IY,K2)
 1562 WWW(K12)=XL(K1X,K2)
      CALL PMXMUL(KMAX,KMAX,KMAX,KMAX,WWW,TK,DUMMY,PTK,FFF,0)
      DO 1563 K=1,KMAX
      DO 1563 J=1,KMAX
      KJ=(J-1)*KMAX+K
 1563 PTK(KJ)=FF(K,J)-PTK(KJ)
      MKM=KMAX*(KMAX+2)
      CALL PMXIV(KMAX,MKM,PTK,PTKI,XXX,YYY)
      CALL PMXMUL(KMAX,KMAX,KMAX,1,PTKI,WWW,AP,QP,FFF,1)
      SUM1=CMPLX(0.,0.)
      DO 1564 K=1,KMAX
 1564 SUM1=SUM1+QP(K)/FLOAT(KMAX)
      RATIOP=SUM1/AVEQ*VOL
C
      CALL PMXMUL(KMAX,KMAX,KMAX,KMAX,PTKI,WWW,TK,XXX,FFF,1)
      CALL PMXMUL(KMAX,KMAX,1,1,XXX,ZZZ,DUMMY,QP,FFF,0)
      SUMB=CMPLX(0.,0.)
      DO 66 K=1,KMAX
   66 SUMB=SUMB+QP(K)/(QP(K)+ZZZ(K))/FLOAT(KMAX)/VOL
      TQ=SUMB
C
 2000 RATIO=-TQ
C
C
      ICASE=IOCASE
      RETURN
      END
C
C
C
C
C*********************************************************************
      SUBROUTINE MATXIN(N,M,X,XI,ICOUNT)
C*********************************************************************
C    * MATRIX INVERSION BY MATRIX PARTITION METHOD
C    * XI(I,J) : (N X N) MATRIX
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C     * X(I,J) : INVERTED MATRIX
C     * M = N + 1
C
      COMPLEX X(30,30), XI(30,30), Y(30,30)
C
      IF(ICOUNT.GT.1) GO TO 1000
      WRITE(9,54)
   54 FORMAT(10X,'MATRIX A')
      DO 50 I=1,N
   50 WRITE(9,1) (XI(I,J), J=1,N)
    1 FORMAT(/5X,3(3X,2(2X,E10.3)))
 1000 CONTINUE
C
      K = 0
      DO 10 J=1,N
   10 Y(1,J) = 0.
      Y(1,M) = 1.
      DO 11 I=1,N
   11 Y(I,1) = 0.
      Y(M,1) = 1.
  200 DO 20 I=2,M
      II = I - 1
      DO 20 J=2,M
      JJ = J - 1
      Y(I,J) = XI(II,JJ)
   20 CONTINUE
C
      DO 30 I=1,N
      DO 30 J=1,N
      X(I,J) = Y(I,J) - Y(I,M)*Y(M,J)/Y(M,M)
   30 CONTINUE
C
      K = K+1
      IF(K .EQ. N) GO TO 100
      DO 40 I=1,N
      DO 40 J=1,N
      XI(I,J) = X(I,J)
   40 CONTINUE
      GO TO 200
C
  100 DO 89 I=1,N
      DO 89 J=1,N
      X(I,J) = -X(I,J)
   89 CONTINUE
      IF(ICOUNT.GT.1) GO TO 66
      WRITE(9,88)
   88 FORMAT(//////5X,'INVERSE A')
      DO 60 I=1,N
   60 WRITE(9,2) (X(I,J), J=1,N)
    2 FORMAT(/5X,3(3X,2(2X,E10.3)))
   66 RETURN
      END
C
C
C
C**********************************************************************
      SUBROUTINE MATMUL(N,L,KN,M,A,B,C,D,NOP,ICOUNT)
C**********************************************************************
C     * MATRIX MULTIPLICATION
C     * NOP=0 ; D(N,L) = A(N,K) X B(K,L)
```

```
C     *     =1 ; D(N,M) = A(N,K)*B(K,L)*C(L,M)
C
      COMPLEX A(30,30),B(30,30),C(30,30),D(30,30)
      COMPLEX SUM1,SUM2,F(30,30)
C
      DO 10 I=1,N
      DO 10 J=1,L
      SUM1 = CMPLX(0.,0.)
      DO 20 K=1,KN
   20 SUM1 = SUM1 + A(I,K)*B(K,J)
      F(I,J) = SUM1
   10 CONTINUE
      IF(NOP .EQ. 1) GO TO 15
      DO 16 I=1,N
      DO 16 J=1,L
   16 D(I,J) = F(I,J)
      GO TO 17
C
   15 DO 30 I=1,N
      DO 30 J=1,M
      SUM2 = CMPLX(0.,0.)
      DO 40 K=1,N
   40 SUM2 = SUM2 +F(I,K)*C(K,J)
      D(I,J) = SUM2
   30 CONTINUE
C
   17 CONTINUE
      IF(ICOUNT.GT.1) GO TO 67
      WRITE(9,1)
      DO 50 I=1,N
   50 WRITE(9,2) (A(I,J),J=1,KN)
      WRITE(9,3)
      DO 51 I=1,KN
   51 WRITE(9,2) (B(I,J), J=1,L)
      IF(NOP .EQ. 0) GO TO 21
      WRITE(9,5)
      DO 52 I=1,L
   52 WRITE(9,2) (C(I,J), J=1,M)
   21 IF(NOP .EQ. 0) M=L
      WRITE(9,6)
      DO 53 I=1,N
   53 WRITE(9,2) (D(I,J), J=1,M)
CC
    1 FORMAT(///10X,'MATRIX  A(N,N)')
    3 FORMAT(///10X,'MATRIX  B(N,N)')
    5 FORMAT(///10X,'MATRIX  C(N,N+1)')
    6 FORMAT(///10X,'MATRIX  D(N,N+1) = A X B X C')
    2 FORMAT(/5X,3(3X,2(2X,E10.3)))
   67 RETURN
      END
      SUBROUTINE PMXIV(N,M,A,B,WA,WK)
      COMPLEX A(N,N),B(N,N),WA(M)
      DIMENSION WK(N)
      DO 10 I=1,N
      DO 20 J=1,N
      B(I,J)=CMPLX(0.,0.)
      IF(I .EQ. J)B(I,J)=CMPLX(1.,0.)
   20 CONTINUE
   10 CONTINUE
      CALL LEQ2C(A,N,N,B,N,N,0,WA,WK,IER)
      RETURN
      END
      SUBROUTINE PMXMUL(N,KN,L,M,A,B,C,D,F,NOP)
      COMPLEX A(N,KN),B(KN,L),C(L,M),F(N,L),D(N,M)
      COMPLEX SUM1,SUM2
C
      DO 10 I=1,N
      DO 10 J=1,L
      SUM1=CMPLX(0.,0.)
      DO 20 K=1,KN
   20 SUM1=SUM1+A(I,K)*B(K,J)
      F(I,J)=SUM1
   10 CONTINUE
      IF(NOP .EQ. 1)GO TO 15
      DO 16 I=1,N
      DO 16 J=1,L
   16 D(I,J)=F(I,J)
      GO TO 17
   15 DO 30 I=1,N
      DO 30 J=1,M
      SUM2=CMPLX(0.,0.)
      DO 40 K=1,L
   40 SUM2=SUM2+F(I,K)*C(K,J)
      D(I,J)=SUM2
   30 CONTINUE
   17 RETURN
      END
C
C
C******************************************************************
      SUBROUTINE OPEN4(S,RATIO,NCH1,ICOUNT,XMAX4)
C******************************************************************
C
C  ***  CALCULATE OPEN-LOOP TRANSFER FUNCTION  ***
C  ***  S = FREQUENCY
C  ***  RATIO = OPEN-LOOP TRANSFER FUNCTION
C
C
      COMPLEX S,RATIO
      COMPLEX FALF,RAN1,GANM,ZN1,B1,RK1,XZN1,XBM,XRKM,F1
      COMPLEX THFOT,APIP(15,200),XUM(15),XUML, TGAM1,TPI1,
     1        ZI(200,5),AX(200,5),DENO,DENO1,XYZ,Y4,AI1,AIP1,AIP2,
     2        AIP4,FG(100),CFP
      COMPLEX DQ(200),TQ,YP(200),Y(200),AP(30)
      COMPLEX WW1,WW2,TZ1,TZ2,TWO,THREE,WAX,WZL
      COMPLEX XK,XKP,XKRA,XKPRA,RATIOP,RATIOW,
     @     RATIOK,OPTK,OPTH,OPTJ,OPOJ,
     @     QP(30),WL(16),
     @     WKC(16),WKP(4),WKR,WKPR,WKR1,DUM3D(200),
     @     WWW,XXX,YYY,ZZZ,FFF,SUM1,SUMA,SUMB
      DIMENSION WKPR(200)
      DIMENSION XXX(10000),YYY(10000),ZZZ(10000),WWW(10000),
     @          FFF(10000)
      COMMON/VSOS/VOL
      COMMON/SKIN/XK(5,30,5,30),XKP(5,30),XKRA(10,10),XKPRA(10)
      COMMON/GKIN/IKIN,IDCHTY(15,15),ITY(225),JJMX(15),JJDB(15,15),
     @           ITYB(150)
      COMMON/TF/RATIOP,RATIOK,OPTK,OPTH,RATIOW,OPTJ,PTOJ
      COMMON/SIM1/IMAX,JMAX,KMAX,ICASE,ISPEC,JSPEC,INUCLR,XKEFF
      COMMON/SIM2/JMX(20),NFT(15,15,30),AL(15,15),TAL(15,15),
     1              BAL(15,15),ASRC(15,15),SRC(15,15,30),AEXP(15,15),
     2              REXP(15,15,30),AXSRC(30),XXSRC(30)
      COMMON/SIM3/JJD(15,15),DZ1(200),DZ2(200),NF(200,30),NB(200),
     1              SC(200,30,6),XEXP(200,30),SIG1(200,30,11),
     2              CSIG1(200,30,11)
      COMMON/KIN2/RDF(15,15),RCDF(15,15),RANO1(200,4),ADF(30),
     1              ACDF(30),GANOM(200,30,6),CFP
      COMMON/KIN3/RANI(200,4),GANM(200,30,6),ZNI(200,4),BI(200)
      COMMON/KIN5/RKI(200),XZNI(200,30,6),XBM(200,30),XRKM(200,30)
      COMMON/CONS12/ P,VCH,VIN(200),AXS(200),DH(200),DHIN(200),
     1        PH(200),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2        DENSF,VFG1,RHOG,GO(200),GO2(200),HO(200),GC,G1,KLOSS(30),
     3        FRICMO(200),VGJH(200,30),COH(200,30),CZERO,VGJ,DPTS,
     4        GO2RF(200),HFG1,ZSP(30),NUMBSP(200,30),ALHEAT,CXF(200),
     5        AVEQ,CHOMO1,CHOMO2,XKIN(200),XKEXIT(200)
      COMMON/CONSS1/ QDIS(200,30),QO(200,30),DZ(200,30),Z(200,30),
     1        K1(200,30),CKIN(200,30),ZETA(200,30),DOIN(200,30),
     2        DOOUT(200,30),ALPIN(200,30), BEE(200,30),CPI1(200,30),
     3        COR2PH(200,30), ZETSP(200,30), WIN
      COMMON/VOIDPT/FALF(200,30),F1(200), TGAM1(200),TPI1(200)
      COMMON/TWOG2/WAX(100,100),WZL(100,100),TZ1(100,100),
     1              TZ2(100,100),TWO(100,100),THREE(100,100)
      EQUIVALENCE (XXX(1),THREE(1,1)),(YYY(1),TWO(1,1)),
     @              (ZZZ(1),TZ2(1,1)),(WWW(1),TZ1(1,1)),
     @              (FFF(1),WZL(1,1))
C
C
      IOCASE=ICASE
      KKMAX=KMAX
      MM=KKMAX+1
      TQ=CMPLX(0.,0.)
C...........................................................................
C  *  ICASE = 4,  RADIALLY COUPLED KINETICS
C...........................................................................
      MJR=JJMX(IMAX)
      MJJD=JJDB(IMAX,MJR)
      DO 222 IM=1,MJJD
      DO 222 IN=1,MJJD
      WAX(IM,IN)=CMPLX(0.,0.)
      WZL(IM,IN)=CMPLX(0.,0.)
  222 CONTINUE
C
      DO 1200 I=1,IMAX
      JR=JJMX(I)
      IM1=I-1
      IP1=I+1
      IF(I.NE.1) JIM1=JJMX(IM1)
      DO 1200 J=1,JR
      JM1=J-1
      JP1=J+1
      M=JJDB(I,J)
C
      DO 1115 N=1,5
      AX(M,N)=CMPLX(0.,0.)
 1115 ZL(M,N)=CMPLX(0.,0.)
C
      IF(I.EQ.1) GO TO 1117
      IF(J.LE.JR.AND.J.GT.JIM1) GO TO 1117
      IF(I.NE.1) MIM1=JJDB(IM1,J)
 1117 IF(I.NE.IMAX) MIP1=JJDB(IP1,J)
```

```
      IF(J.NE.1) MJM1=JJDB(I,JM1)
      IF(J.NE.JR) MJP1=JJDB(I,JP1)
      MYIM1=ITY(MIM1)
      MYJM1=ITY(MJM1)
      MY=ITY(M)
      MYIP1=ITY(MIP1)
      MYJP1=ITY(MJP1)
C
      IF(I.EQ.1) GO TO 1120
      IF(I.EQ.IMAX) GO TO 1130
      IF(J.EQ.1) GO TO 1140
      IF(J.EQ.JR) GO TO 1150
      IF(J.LT.JR.AND.J.GT.JIM1) GO TO 1160
      ANOMQ=RANOI(M,1)*ASRC(IM1,J)+RANOI(M,2)*ASRC(I,JM1)+
     1      RANOI(M,3)*ASRC(IP1,J)+RANOI(M,4)*ASRC(I,JP1)
      AX(M,1)=-RANI(M,1)
      ZL(M,1)=-ZNI(M,1)*ASRC(IM1,J)*AVEQ
      AX(M,2)=-RANI(M,2)
      ZL(M,2)=-ZNI(M,2)*ASRC(I,JM1)*AVEQ
      AX(M,3)=BI(M)
      ZL(M,3)=(RKI(M)+RCDF(I,J)/RDF(I,J)*ANOMQ)*AVEQ
      AX(M,4)=-RANI(M,4)
      ZL(M,4)=-ZNI(M,4)*ASRC(I,JP1)*AVEQ
      AX(M,5)=-RANI(M,3)
      ZL(M,5)=-ZNI(M,3)*ASRC(IP1,J)*AVEQ
      IR=JJDB(IM1,J)
      WAX(M,IR)=AX(M,1)
      WZL(M,IR)=ZL(M,1)
      IR=JJDB(I,JM1)
      WAX(M,IR)=AX(M,2)
      WZL(M,IR)=ZL(M,2)
      IR=JJDB(I,J)
      WAX(M,IR)=AX(M,3)
      WZL(M,IR)=ZL(M,3)
      IR=JJDB(I,JP1)
      WAX(M,IR)=AX(M,4)
      WZL(M,IR)=ZL(M,4)
      IR=JJDB(IP1,J)
      WAX(M,IR)=AX(M,5)
      WZL(M,IR)=ZL(M,5)
      Y(M)=ZL(M,1)*F1(MYIM1)+ZL(M,2)*F1(MYJM1)+ZL(M,3)*F1(MY)+
     1     ZL(M,4)*F1(MYJP1)+ZL(M,5)*F1(MYIP1)
      GO TO 1180
C
C    *****   I = 1   *****
C
 1120 AX(M,5)=-RANI(M,3)
      ZL(M,5)=-ZNI(M,3)*ASRC(IP1,J)*AVEQ
      IR=JJDB(IP1,J)
      WAX(M,IR)=AX(M,5)
      WZL(M,IR)=ZL(M,5)
      IF(J.EQ.1) GO TO 1124
      AX(M,1)=-RANI(M,2)
      ZL(M,1)=-ZNI(M,2)*ASRC(IM1,J)*AVEQ
      IR=JJDB(IM1,J)
      WAX(M,IR)=AX(M,1)
      WZL(M,IR)=ZL(M,1)
      AX(M,2)=BI(M)
      WAX(M,M)=AX(M,2)
      IF(J.EQ.JR) GO TO 1126
      ANOMQ=RANOI(M,2)*ASRC(I,JM1)+
     1        RANOI(M,3)*ASRC(IP1,J)+RANOI(M,4)*ASRC(I,JP1)
      ZL(M,2)=(RKI(M)+RCDF(I,J)/RDF(I,J)*ANOMQ)*AVEQ
      WZL(M,M)=ZL(M,2)
      AX(M,3)=-RANI(M,4)
      ZL(M,3)=-ZNI(M,4)*ASRC(I,JP1)*AVEQ
      IR=JJDB(I,JP1)
      WAX(M,IR)=AX(M,3)
      WZL(M,IR)=ZL(M,3)
      Y(M)=ZL(M,1)*F1(MYJM1)+ZL(M,2)*F1(MY)+
     1      ZL(M,3)*F1(KYIP1)+ZL(M,5)*F1(MYJP1)
      GO TO 1180
C
C  *****   I = 1,  J = 1   *****
C
 1124 ANOMQ=RANOI(M,2)*ASRC(I,J)+RANOI(M,3)*ASRC(IP1,J)+
     1        RANOI(M,4)*ASRC(I,JP1)
      AX(M,1)=BI(M)-RANI(M,2) .
      ZL(M,1)=(RKI(M)+RCDF(I,J)/RDF(I,J)*ANOMQ-ZNI(M,2)*ASRC(I,J))*AVEQ
      AX(M,2)=-RANI(M,4)
      ZL(M,2)=-ZNI(M,4)*ASRC(I,JP1)*AVEQ
      IR=JJDB(I,J)
      WAX(M,IR)=AX(M,1)
      WZL(M,IR)=ZL(M,1)
      IR=JJDB(I,JP1)
      WAX(M,IR)=AX(M,2)
      WZL(M,IR)=ZL(M,2)
      Y(M)=ZL(M,1)*F1(MY)+ZL(M,2)*F1(MYJP1)+ZL(M,5)*F1(MYIP1)
      GO TO 1180
C
C   *****    I = 1,  J = JR   *****
C
 1126 ANOMQ=RANOI(M,2)*ASRC(I,JM1)+RANOI(M,3)*ASRC(IP1,J)
      ZL(M,2)=(RKI(M)+RCDF(I,J)/RDF(I,J)*ANOMQ)*AVEQ
      IR=JJDB(I,J)
      WZL(M,IR)=ZL(M,2)
      Y(M)=ZL(M,1)*F1(MYJM1)+ZL(M,2)*F1(MY)+ZL(M,5)*F1(MYIP1)
      GO TO 1180
C
C   *****   I = IMAX   *****
C
 1130 AX(M,1)=-RANI(M,1)
      ZL(M,1)=-ZNI(M,1)*ASRC(IM1,J)*AVEQ
      IR=JJDB(IM1,J)
      WAX(M,IR)=AX(M,1)
      WZL(M,IR)=ZL(M,1)
      IF(J.EQ.1) GO TO 1133
      AX(M,2)=-RANI(M,2)
      ZL(M,2)=-ZNI(M,2)*ASRC(I,JM1)*AVEQ
      AX(M,3)=BI(M)-RANI(M,3)
      IR=JJDB(I,JM1)
      WAX(M,IR)=AX(M,2)
      WZL(M,IR)=ZL(M,2)
      WAX(M,M)=AX(M,3)
      IF(J.EQ.JR) GO TO 1136
      ANOMQ=RANOI(M,1)*ASRC(IM1,J)+RANOI(M,2)*ASRC(I,JM1)+
     1        RANOI(M,3)*ASRC(I,J)+RANOI(M,4)*ASRC(I,JP1)
      ZL(M,3)=(RKI(M)+RCDF(I,J)/RDF(I,J)*ANOMQ)*AVEQ
      AX(M,4)=-RANI(M,4)
      ZL(M,4)=-ZNI(M,4)*ASRC(I,JP1)*AVEQ
      WZL(M,M)=ZL(M,3)
      IR=JJDB(I,JP1)
      WAX(M,IR)=AX(M,4)
      WZL(M,IR)=ZL(M,4)
      Y(M)=ZL(M,1)*F1(MYIM1)+ZL(M,2)*F1(MYJM1)+ZL(M,3)*F1(MY)+
     1     ZL(M,4)*F1(MYJP1)
      GO TO 1180
C
C    *****   J = 1,  I = IMAX   *****
C
 1133 ANOMQ=RANOI(M,1)*ASRC(IM1,J)+RANOI(M,2)*ASRC(I,J)+
     1        RANOI(M,3)*ASRC(I,J)+RANOI(M,4)*ASRC(I,JP1)
      AX(M,3)=BI(M)-RANI(M,2)-RANI(M,3)
      ZL(M,3)=(RKI(M)+RCDF(I,J)/RDF(I,J)*ANOMQ-(ZNI(M,2)+
     1           ZNI(M,3))*ASRC(I,J))*AVEQ
      AX(M,4)=-RANI(M,4)
      ZL(M,4)=-ZNI(M,4)*ASRC(I,JP1)*AVEQ
      WAX(M,M)=AX(M,3)
      WZL(M,M)=ZL(M,3)
      IR=JJDB(I,JP1)
      WAX(M,IR)=AX(M,4)
      WZL(M,IR)=ZL(M,4)
      Y(M)=ZL(M,1)*F1(MYIM1)+ZL(M,4)*F1(MYJP1)+ZL(M,3)*F1(MY)
      GO TO 1180
C
C    *****   J = JR,  I = IMAX   *****
C
 1136 ANOMQ=RANOI(M,1)*ASRC(IM1,J)+RANOI(M,2)*ASRC(I,JM1)+
     1        RANOI(M,3)*ASRC(I,J)
      ZL(M,3)=(RKI(M)+RCDF(I,J)/RDF(I,J)*ANOMQ-ZNI(M,3)*ASRC(I,J))*AVEQ
      WZL(M,M)=..(M,3)
      Y(M)=ZL(M,1)*F1(MYIM1)+ZL(M,2)*F1(MYJM1)+ZL(M,3)*F1(MY)
      GO TO 1180
C
C    *****   J = 1,  I.NE.1,  I.NE.IMAX   *****
C
 1140 AX(M,1)=-RANI(M,1)
      ZL(M,1)=-ZNI(M,1)*ASRC(IM1,J)*AVEQ
      AX(M,4)=-RANI(M,4)
      ZL(M,4)=-ZNI(M,4)*ASRC(I,JP1)*AVEQ
      AX(M,5)=-RANI(M,3)
      ZL(M,5)=-ZNI(M,3)*ASRC(IP1,J)*AVEQ
      ANOMQ=RANOI(M,1)*ASRC(IM1,J)+RANOI(M,2)*ASRC(I,J)+
     1        RANOI(M,3)*ASRC(IP1,J)+RANOI(M,4)*ASRC(I,JP1)
      AX(M,3)=BI(M)-RANI(M,2)
      ZL(M,3)=(RKI(M)+RCDF(I,J)/RDF(I,J)*ANOMQ-ZNI(M,2)*
     1           ASRC(I,J))*AVEQ
      IR=JJDB(IM1,J)
      WAX(M,IR)=AX(M,1)
      WZL(M,IR)=ZL(M,1)
      IR=JJDB(I,JP1)
      WAX(M,IR)=AX(M,4)
      WZL(M,IR)=ZL(M,4)
      IR=JJDB(IP1,J)
      WAX(M,IR)=AX(M,5)
      WZL(M,IR)=ZL(M,5)
      IR=JJDB(I,J)
      WAX(M,IR)=AX(M,3)
      WZL(M,IR)=ZL(M,3)
      Y(M)=ZL(M,1)*F1(MYIM1)+ZL(M,3)*F1(MY)+
     1     ZL(M,4)*F1(MYJP1)+ZL(M,5)*F1(MYIP1)
      GO TO 1180
C
C     *****   J = JR,  I.NE.1,  I.NE.IMAX   *****
C
 1150 AX(M,2)=-RANI(M,2)
      ZL(M,2)=-ZNI(M,2)*ASRC(I,JM1)*AVEQ
      AX(M,3)=BI(M)
      AX(M,5)=-RANI(M,3)
      ZL(M,5)=-ZNI(M,3)*ASRC(IP1,J)*AVEQ
      IR=JJDB(I,JM1)
      WAX(M,IR)=AX(M,2)
      WZL(M,IR)=ZL(M,2)
      IR=M
      WAX(M,IR)=AX(M,3)
      IR=JJDB(IP1,J)
      WAX(M,IR)=AX(M,5)
      WZL(M,IR)=ZL(M,5)
      IF(J.EQ.JIM1) GO TO 1153
      ANOMQ=RANOI(M,2)*ASRC(I,JM1)+RANOI(M,3)*ASRC(IP1,J)
      ZL(M,3)=(RKI(M)+RCDF(I,J)/RDF(I,J)*ANOMQ)*AVEQ
      IR=M
      WZL(M,IR)=ZL(M,3)
      Y(M)=ZL(M,2)*F1(MYJM1)+ZL(M,3)*F1(MY)+ZL(M,5)*F1(MYIP1)
      GO TO 1180
 1153 ANOMQ=RANOI(M,1)*ASRC(IM1,J)+RANOI(M,2)*ASRC(I,JM1)+
     1     RANOI(M,3)*ASRC(IP1,J)
      AX(M,1)=-RANI(M,1)
      ZL(M,1)=-ZNI(M,1)*ASRC(IM1,J)*AVEQ
      ZL(M,3)=(RKI(M)+RCDF(I,J)/RDF(I,J)*ANOMQ)*AVEQ
      Y(M)=ZL(M,1)*F1(MYIM1)+ZL(M,2)*F1(MYJM1)+ZL(M,3)*F1(MY)+
     1     ZL(M,5)*F1(MYIP1)
      GO TO 1180
C
C     *****   J.LT.JR.AND.J.GT.JIM1,  I.NE.1,  I.NE.IMAX   *****
C
 1160 AX(M,2)=-RANI(M,2)
      ZL(M,2)=-ZNI(M,2)*ASRC(I,JM1)*AVEQ
      ANOMQ=RANOI(M,2)*ASRC(I,JM1)+
     1       RANOI(M,3)*ASRC(IP1,J)+RANOI(M,4)*ASRC(I,JP1)
      AX(M,3)=BI(M)
      ZL(M,3)=(RKI(M)+RCDF(I,J)/RDF(I,J)*ANOMQ)*AVEQ
      AX(M,4)=-RANI(M,4)
      ZL(M,4)=-ZNI(M,4)*ASRC(I,JP1)*AVEQ
      AX(M,5)=-RANI(M,3)
      ZL(M,5)=-ZNI(M,3)*ASRC(IP1,J)*AVEQ
      IR=JJDB(I,JM1)
      WAX(M,IR)=AX(M,2)
      WZL(M,IR)=ZL(M,2)
      IR=M
      WAX(M,IR)=AX(M,3)
      WZL(M,IR)=ZL(M,3)
      IR=JJDB(I,JP1)
      WAX(M,IR)=AX(M,4)
      WZL(M,IR)=ZL(M,4)
      IR=JJDB(IP1,J)
      WAX(M,IR)=AX(M,5)
      WZL(M,IR)=ZL(M,5)
      Y(M)=ZL(M,2)*F1(MYJM1)+ZL(M,3)*F1(MY)+
     1     ZL(M,4)*F1(MYJP1)+ZL(M,5)*F1(MYIP1)
 1180 CONTINUE
C
      DO 1161 N=1,5
      ZL(M,N) = CFP*ZL(M,N)
 1161 CONTINUE
C
      DQ(M)=CMPLX(0.,0.)
      YP(M)=CMPLX(0.,0.)
      DO 1185 JPO=1,JMAX
 1185 APIP(JPO,M)=CMPLX(0.,0.)
      IT=IDCHTY(I,J)
      WKPR(M)=XKPRA(IT)
      SUMQ=0.
      DO 335 K=1,KMAX
  335 SUMQ=SUMQ+QDIS(IT,K)
      Y(M)=SUMQ/KMAX/AVEQ
      MJR=JJMX(IMAX)
      NCH8=JJDB(IMAX,MJR)
      DO 1164 IR=1,NCH8
      IY=ITY8(IR)
      MIR=(IR-1)*NCH8+M
 1164 ZZZ(MIR)=XKRA(IT,IY)
C
 1200 CONTINUE
      DO 1162 I=1,NCH8
      DO 1163 J=1,NCH8
      WZL(I,J)=CFP*WZL(I,J)
 1163 CONTINUE
 1162 CONTINUE
      DO 1167 I=1,NCH8
      DO 1167 J=1,NCH8
      IJ=(J-1)*NCH8+I
 1167 XXX(IJ)=WZL(I,J)
      CALL PMXMUL(NCH8,NCH8,NCH8,1,XXX,ZZZ,DQ,WWW,FFF,0)
      DO 1165 I=1,NCH8
      DO 1165 J=1,NCH8
      IJ=(J-1)*NCH8+I
 1165 WWW(IJ)=WAX(I,J)-WWW(IJ)
      MNCH=NCH8*(NCH8+2)
      CALL PMXIV(NCH8,MNCH,WWW,YYY,ZZZ,FFF)
      CALL PMXMUL(NCH8,NCH8,NCH8,1,YYY,XXX,WKPR,DQ,FFF,1)
      SUM1=CMPLX(0.,0.)
      DO 1166 I=1,NCH8
 1166 SUM1=SUM1+DQ(I)/FLOAT(NCH8)
      RATIOP=SUM1/AVEQ*VOL
C
C
      CALL PMXMUL(NCH8,NCH8,NCH8,NCH8,YYY,XXX,ZZZ,WWW,FFF,1)
      CALL PMXMUL(NCH8,NCH8,1,1,WWW,Y,DUM3D,DQ,FFF,0)
      SUMB=CMPLX(0.,0.)
      DO 1172 I=1,NCH8
 1172 SUMB=SUMB+DQ(I)/(DQ(I)+Y(I))/FLOAT(NCH8)
      IQ=SUMB
      RATIO=-IQ
      ICASE=IOCASE
      RETURN
      END
C
C
C*****************************************************************
```

420

```fortran
      SUBROUTINE OPEN8(S,RATIO,NCH1,ICOUNT,KHAX4)
C***********************************************************************
C
C  ***  CALCULATE OPEN-LOOP TRANSFER FUNCTION  ***
C  ***  S = FREQUENCY
C  ***  RATIO = OPEN-LOOP TRANSFER FUNCTION
C
C
      COMPLEX S,RATIO
      COMPLEX FALF,RANI,GANM,ZNI,BI,RKI,XZNI,XBM,XRKM,F1
      COMPLEX THEO1,APIP(15,200),XUM(15),XUML, TGAM1,TPI1,
     1        ZI(200,5),AX(200,5),DENO,DENO1,XYZ,Y4,AI1,AIP1,AIP2,
     2        AIP4,FG(100),CFP
      COMPLEX DQ(200),TQ,YP(200),Y(200),AP(30)
      COMPLEX WW1,WW2,TZ1,TZ2,TWO,THREE,WAX,WZL
      COMPLEX XK,XKP,XKRA,XKPRA,RATIOP,RATIOW,
     @     RATIOK,OPTK,OPTH,OPTJ,OPOJ,
     @     QP(30),XKC(200,5),WL(16),
     @     WKC(16),WKP(4),WKR,WKPR,WKRI,DUM3D(200),
     @     WWW,XXX,YYY,ZZZ,FFF,SUM1,SUMA,SUMB
      DIMENSION WKPR(200)
      DIMENSION XXX(10000),YYY(10000),ZZZ(10000),WWW(10000),
     @          FFF(10000)
      COMMON/VSOS/VOL
      COMMON/SKIN/XK(5,30,5,30),XKP(5,30),XKRA(10,10),XKPRA(10)
      COMMON/GKIN/IKIN,IDCHTY(15,15),ITY(225),JJMX(15),JJDB(15,15),
     @           ITYB(150)
      COMMON/TF/RATIOP,RATIOK,OPTK,OPTH,RATIOW,OPTJ,PTOJ
      COMMON/SIM1/IMAX,JMAX,KMAX,ICASE,ISPEC,JSPEC,INUCLR,XKEFF
      COMMON/SIM2/JMX(20),NFT(15,15,30),AL(15,15),TAL(15,15),
     1           BAL(15,15),ASRC(15,15),SRC(15,15,30),AEXP(15,15),
     2           REXP(15,15,30),AXSRC(30),XXSRC(30)
      COMMON/SIM3/JJD(15,15),DZ1(200),DZ2(200),NF(200,30),NB(200),
     1           SC(200,30,6),XEXP(200,30),SIG1(200,30,11),
     2           CSIG1(200,30,11)
      COMMON/KIN2/RDF(15,15),RCDF(15,15),RANO1(200,4),ADF(30),
     1           ACDF(30),GANOM(200,30,6),CFP
      COMMON/KIN3/RANI(200,4),GANM(200,30,6),ZNI(200,4),BI(200)
      COMMON/KIN5/RKI(200),XZNI(200,30,6),XBM(200,30),XRKM(200,30)
      COMMON/CONS12/ P,VCH,VIN(200),AXS(200),DH(200),DHIN(200),
     1      PH(200),TIN,TSATP,ENTHT,DENSI,SIGM,ENTHP,VISC,CPF,KF,
     2      DENSF,VFG1,RHOG,G0(200),G02(200),H0(200),GC,G1,KLOSS(30),
     3      FRICMO(200),VGJH(200,30),COH(200,30),CZERO,VGJ,DPTS,
     4      G02RF(200),HFG1,ZSP(30),NUMBSP(200,30),ALHEAT,CXF(200),
     5      AVEQ,CHOMO1,CHOMO2,XKIN(200),XKEXIT(200)
      COMMON/CONSS1/ QDIS(200,30),Q0(200,30),DZ(200,30),Z(200,30),
     1      K1(200,30),CKIN(200,30),ZETA(200,30),DOIN(200,30),
     2      DOOUT(200,30),ALPIN(200,30), BEE(200,30),CPI1(200,30),
     3      COR2PH(200,30), ZETSP(200,30), WIN
      COMMON/VOIDPT/FALF(200,30),F1(200), TGAM1(200),TPI1(200)
      COMMON/TWOG2/WAX(100,100),WZL(100,100),TZ1(100,100),
     1           TZ2(100,100),TWO(100,100),THREE(100,100)
      EQUIVALENCE (XXX(1),THREE(1,1)),(YYY(1),TWO(1,1)),
     @           (ZZZ(1),TZ2(1,1)),(WWW(1),TZ1(1,1)),
     @           (FFF(1),WZL(1,1))
C
C
      IOCASE=ICASE
      KKMAX=KMAX
      MM=KKMAX+1
      TQ=CMPLX(0.,0.)
C
C...........................................................................
C   *  ICASE = 8 ,  3D COUPLED KINETICS TRANSFER FUNCTION
C                   CHECKER-BOARD PROBLEM ONLY
C...........................................................................
      IX=4*KMAX
      DO 91 MX=1,IX
      DO 91 NY=1,IX
      WAX(MX,NY)=CMPLX(0.,0.)
   91 WZL(MX,NY)=CMPLX(0.,0.)
      DO 450 K=1,KMAX
      KM1=K-1
      DO 450 I=1,2
      JR=JMX(I)
      DO 450 J=1,2
      MX=1+2*(I-1)+(J-1)+4*(K-1)
      MXM4=MX-4
      MXP4=MX+4
      MXM2=MX-2
      MXP2=MX+2
      MXM1=MX-1
      MXP1=MX+1
      IS=ISPEC+I-1
      JS=JSPEC+J-1
      M=JJD(IS,JS)
      ANOMQ=0.
      MI=MX
      DO 402 N=1,6
  402 ANOMQ=ANOMQ+GANOM(M,K,N)*SC(M,K,N)
C
      IF(K.EQ.1) GO TO 420
      AX(MI,5)=CMPLX(0.,0.)
      AX(MI,1)=-GANM(M,K,5)
      ZL(MI,5)=CMPLX(0.,0.)
      ZL(MI,1)=-XZNI(M,K,5)*SC(M,K,5)*AVEQ
      IF(K.NE.KMAX) GO TO 404
      WAX(MX,MXM4)=AX(MI,1)
      WZL(MX,MXM4)=ZL(MI,1)
      GO TO 405
  404 AX(MI,5)=-GANM(M,K,6)
      ZL(MI,5)=-XZNI(M,K,6)*SC(M,K,6)*AVEQ
      WAX(MX,MXP4)=AX(MI,5)
      WZL(MX,MXP4)=ZL(MI,5)
  405 IF(I.EQ.1.AND.J.EQ.1) GO TO 407
      IF(I.EQ.1.AND.J.EQ.2) GO TO 410
      IF(I.EQ.2.AND.J.EQ.1) GO TO 415
C
      AX(MI,2)=-GANM(M,K,1)-GANM(M,K,3)
      ZL(MI,2)=(-XZNI(M,K,1)*SC(M,K,1)-XZNI(M,K,3)*SC(M,K,3))*AVEQ
      AX(MI,3)=-GANM(M,K,2)-GANM(M,K,4)
      ZL(MI,3)=(-XZNI(M,K,2)*SC(M,K,2)-XZNI(M,K,4)*SC(M,K,4))*AVEQ
      AX(MI,4)=XBM(M,K)
      ZL(MI,4)=(XRKM(M,K)*SRC(I,J,K)+CSIG1(M,K,3)/SIG1(M,K,3)*
     1           ANOMQ)*AVEQ
      WAX(MX,MXM2)=AX(MI,2)
      WZL(MX,MXM2)=ZL(MI,2)
      WAX(MX,MXM1)=AX(MI,3)
      WZL(MX,MXM1)=ZL(MI,3)
      WAX(MX,MX)=AX(MI,4)
      WZL(MX,MX)=ZL(MT,4)
      GO TO 450
C
  407 AX(MT,4)=-GANM(M,K,1)-GANM(M,K,3)
      ZL(MT,4)=(-XZNI(M,K,1)*SC(M,K,1)-XZNI(M,K,3)*SC(M,K,3))*AVEQ
      AX(MT,3)=-GANM(M,K,2)-GANM(M,K,4)
      ZL(MT,3)=(-XZNI(M,K,2)*SC(M,K,2)-XZNI(M,K,4)*SC(M,K,4))*AVEQ
      AX(MT,2)=XBM(M,K)
      ZL(MT,2)=(XRKM(M,K)*SRC(I,J,K)+CSIG1(M,K,3)/SIG1(M,K,3)*
     1           ANOMQ)*AVEQ
      WAX(MX,MXP2)=AX(MT,4)
      WZL(MX,MXP2)=ZL(MT,4)
      WAX(MX,MXP1)=AX(MT,3)
      WZL(MX,MXP1)=ZL(MT,3)
      WAX(MX,MX)=AX(MT,2)
      WZL(MX,MX)=ZL(MT,2)
      GO TO 450
C
  410 AX(MT,4)=-GANM(M,K,1)-GANM(M,K,3)
      ZL(MT,4)=(-XZNI(M,K,1)*SC(M,K,1)-XZNI(M,K,3)*SC(M,K,3))*AVEQ
      AX(MT,2)=-GANM(M,K,2)-GANM(M,K,4)
      ZL(MT,2)=(-XZNI(M,K,2)*SC(M,K,2)-XZNI(M,K,4)*SC(M,K,4))*AVEQ
      AX(MT,3)=XBM(M,K)
      ZL(MT,3)=(XRKM(M,K)*SRC(I,J,K)+CSIG1(M,K,3)/SIG1(M,K,3)*
     1           ANOMQ)*AVEQ
      WAX(MX,MXP2)=AX(MT,4)
      WZL(MX,MXP2)=ZL(MT,4)
      WAX(MX,MXM1)=AX(MT,2)
      WZL(MX,MXM1)=ZL(MT,2)
      WAX(MX,MX)=AX(MT,3)
      WZL(MX,MX)=ZL(MT,3)
      GO TO 450
C
  415 AX(MT,2)=-GANM(M,K,1)-GANM(M,K,3)
      ZL(MT,2)=(-XZNI(M,K,1)*SC(M,K,1)-XZNI(M,K,3)*SC(M,K,3))*AVEQ
      AX(MT,4)=-GANM(M,K,2)-GANM(M,K,4)
      ZL(MT,4)=(-XZNI(M,K,2)*SC(M,K,2)-XZNI(M,K,4)*SC(M,K,4))*AVEQ
      AX(MT,3)=XBM(M,K)
      ZL(MT,3)=(XRKM(M,K)*SRC(I,J,K)+CSIG1(M,K,3)/SIG1(M,K,3)*
     1           ANOMQ)*AVEQ
      WAX(MX,MXM2)=AX(MT,2)
      WZL(MX,MXM2)=ZL(MT,2)
      WAX(MX,MXP1)=AX(MT,4)
      WZL(MX,MXP1)=ZL(MT,4)
      WAX(MX,MX)=AX(MT,3)
      WZL(MX,MX)=ZL(MT,3)
      GO TO 450
C
  420 CONTINUE
      AX(MT,5)=-GANM(M,K,6)
      ZL(MT,5)=-XZNI(M,K,6)*SC(M,K,6)*AVEQ
      WAX(MX,MXP4)=AX(MT,5)
      WZL(MX,MXP4)=ZL(MT,5)
      IF(I.EQ.1.AND.J.EQ.1) GO TO 425
      IF(I.EQ.1.AND.J.EQ.2) GO TO 430
      IF(I.EQ.2.AND.J.EQ.1) GO TO 435
C
      AX(MT,1)=CMPLX(0.,0.)
      ZL(MT,1)=CMPLX(0.,0.)
C
```

423

```
      AX(MT,2)=-GANM(M,K,1)-GANM(M,K,3)
      ZL(MT,2)=(-XZN1(M,K,1)*SC(M,K,1)-XZN1(M,K,3)*SC(M,K,3))*AVEQ
      AX(MT,3)=-GANM(M,K,2)-GANM(M,K,4)
      ZL(MT,3)=(-XZN1(M,K,2)*SC(M,K,2)-XZN1(M,K,4)*SC(M,K,4))*AVEQ
      AX(MT,4)=XBM(M,K)
      ZL(MT,4)=(XRKM(M,K)*SRC(I,J,K)+CSIG1(M,K,3)/SIG1(M,K,3)*
     1         ANOMQ)*AVEQ
      WAX(MX,MXM2)=AX(MT,2)
      WZL(MX,MXM2)=ZL(MT,2)
      WAX(MX,MXM1)=AX(MT,3)
      WZL(MX,MXM1)=ZL(MT,3)
      WAX(MX,MX)=AX(MT,4)
      WZL(MX,MX)=ZL(MT,4)
      GO TO 450
C
  425 AX(MT,3)=-GANM(M,K,1)-GANM(M,K,3)
      ZL(MT,3)=(-XZN1(M,K,1)*SC(M,K,1)-XZN1(M,K,3)*SC(M,K,3))*AVEQ
      AX(MT,2)=-GANM(M,K,2)-GANM(M,K,4)
      ZL(MT,2)=(-XZN1(M,K,2)*SC(M,K,2)-XZN1(M,K,4)*SC(M,K,4))*AVEQ
      AX(MT,1)=XBM(M,K)
      ZL(MT,1)=(XRKM(M,K)*SRC(I,J,K)+CSIG1(M,K,3)/SIG1(M,K,3)*
     1         ANOMQ)*AVEQ
      AX(MT,4)=CMPLX(0.,0.)
      ZL(MT,4)=CMPLX(0.,0.)
      WAX(MX,MXP2)=AX(MT,3)
      WZL(MX,MXP2)=ZL(MT,3)
      WAX(MX,MXP1)=AX(MT,2)
      WZL(MX,MXP1)=ZL(MT,2)
      WAX(MX,MX)=AX(MT,1)
      WZL(MX,MX)=ZL(MT,1)
      GO TO 450
  430 AX(MT,4)=-GANM(M,K,1)-GANM(M,K,3)
      ZL(MT,4)=(-XZN1(M,K,1)*SC(M,K,1)-XZN1(M,K,3)*SC(M,K,3))*AVEQ
      AX(MT,1)=-GANM(M,K,2)-GANM(M,K,4)
      ZL(MT,1)=(-XZN1(M,K,2)*SC(M,K,2)-XZN1(M,K,4)*SC(M,K,4))*AVEQ
      AX(MT,2)=XBM(M,K)
      ZL(MT,2)=(XRKM(M,K)*SRC(I,J,K)+CSIG1(M,K,3)/SIG1(M,K,3)*
     1         ANOMQ)*AVEQ
      AX(MT,3)=CMPLX(0.,0.)
      ZL(MT,3)=CMPLX(0.,0.)
      WAX(MX,MXP2)=AX(MT,4)
      WZL(MX,MXP2)=ZL(MT,4)
      WAX(MX,MXM1)=AX(MT,1)
      WZL(MX,MXM1)=ZL(MT,1)
      WAX(MX,MX)=AX(MT,2)
      WZL(MX,MX)=ZL(MT,2)
      GO TO 450
C
  435 AX(MT,1)=-GANM(M,K,1)-GANM(M,K,3)
      ZL(MT,1)=(-XZN1(M,K,1)*SC(M,K,1)-XZN1(M,K,3)*SC(M,K,3))*AVEQ
      AX(MT,4)=-GANM(M,K,2)-GANM(M,K,4)
      ZL(MT,4)=(-XZN1(M,K,2)*SC(M,K,2)-XZN1(M,K,4)*SC(M,K,4))*AVEQ
      AX(MT,3)=XBM(M,K)
      ZL(MT,3)=(XRKM(M,K)*SRC(I,J,K)+CSIG1(M,K,3)/SIG1(M,K,3)*
     1         ANOMQ)*AVEQ
      AX(MT,2)=CMPLX(0.,0.)
      ZL(MT,2)=CMPLX(0.,0.)
      WAX(MX,MXM2)=AX(MT,1)
      WZL(MX,MXM2)=ZL(MT,1)
      WAX(MX,MXP1)=AX(MT,4)
      WZL(MX,MXP1)=ZL(MI,4)
      WAX(MX,MX)=AX(MI,3)
      WZL(MX,MX)=ZL(MI,3)
  450 CONTINUE
      DO 451 M=1,MT
      DO 451 J=1,5
      ZL(M,J) = CFP*ZL(M,J)
  451 CONTINUE
      DO 92 MX=1,IX
      DO 92 NY=1,IX
   92 WZL(MX,NY)=CFP*WZL(MX,NY)
      II=0
   99 II=II+1
      IF(II .GT. 4)GO TO 100
      KXI=1+(II-1)*KMAX
      KXF=II*KMAX
      IJ=0
  109 IJ=IJ+1
      IF(IJ .GT. 4)GO TO 105
      KYI=1+(IJ-1)*KMAX
      XYF=IJ*KMAX
      DO 101 KX=KXI,KXF
      DO 102 KY=KYI,KYF
      KXY=(KY-1)*KMAX4+KX
      IKX=II+4*(KX-(II-1)*KMAX-1)
      IKY=IJ+4*(KY-(IJ-1)*KMAX-1)
      XXX(KXY)=WZL(IKX,IKY)
      YYY(KXY)=WAX(IKX,IKY)
  102 CONTINUE
  101 CONTINUE
      GO TO 109
  105 GO TO 99
  100 CONTINUE
      DO 110 I1=1,2
      DO 110 J1=1,2
      DO 110 K1X=1,KMAX
      M1=IDCHTY(I1,J1)
      KX=1+(I1-1)*2+(J1-1)+(K1X-1)*4
      WKPR(KX)=XKP(M1,K1X)
      Y(KX)=QDIS(M1,K1X)/AVEQ
      DO 112 I2=1,2
      DO 112 J2=1,2
      DO 112 K2=1,KMAX
      M2=IDCHTY(I2,J2)
      KY=1+(I2-1)*2+(J2-1)+(K2-1)*4
      KXY=(KY-1)*KMAX4+KX
      ZZZ(KXY)=XK(M1,K1X,M2,K2)
  112 CONTINUE
  110 CONTINUE
      CALL PMXMUL(KMAX4,KMAX4,KMAX4,1,XXX,ZZZ,DUM3D,WWW,
     @               FFF,0)
      DO 113 KX=1,KMAX4
      DO 113 KY=1,KMAX4
      KXY=(KY-1)*KMAX4+KX
  113 WWW(KXY)=YYY(KXY)-WWW(KXY)
      MKM=KMAX4*(KMAX4+2)
      CALL PMXIV(KMAX4,MKM,WWW,YYY,ZZZ,FFF)
      CALL PMXMUL(KMAX4,KMAX4,KMAX4,KMAX4,YYY,XXX,WKPR,DUM3D,
     @               FFF,1)
      SUM1=CMPLX(0.,0.)
      DO 115 K=1,KMAX4
  115 SUM1=SUM1+DUM3D(K)/FLOAT(KMAX4)
      RATIOP=SUM1/AVEQ*VOL
      CALL PMXMUH(KMAX4,KMAX4,KMAX4,KMAX4,YYY,XXX,ZZZ,WWW,FFF,1)
      CALL PMXMUH(KMAX4,KMAX4,1,1,WWW,Y,DUM3D,DQ,FFF,0)
      SUMB=CMPLX(0.,0.)
      DO 117 K=1,KMAX4
  117 SUMB=SUMB+DQ(K)/(DQ(K)+Y(K))/FLOAT(KMAX4)/VOL
      TQ=SUMB
C
C
      RATIO=-TQ
      ICASE=IOCASE
      RETURN
      END
C SVD PROGRAM
C
C
      SUBROUTINE SVD(NM,M,N,A,W,MATU,U,MATV,V,IERR,RV1)
      DIMENSION A(NM,N),W(N),U(NM,N),V(NM,N),RV1(N)
      LOGICAL MATU,MATV
      IERR=0
      DO 100 I=1,M
      DO 100 J=1,N
      U(I,J)=A(I,J)
  100 CONTINUE
      G=0.0
      SCALE=0.0
      ANORM=0.0
      DO 300 I=1,N
      L=I+1
      RV1(I)=SCALE*G
      G=0.0
      S=0.0
      SCALE=0.0
      IF(I .GT. M)GO TO 210
      DO 120 K=I,M
  120 SCALE=SCALE+ABS(U(K,I))
      IF(SCALE .EQ. 0.0)GO TO 210
      DO 130 K=I,M
      U(K,I)=U(K,I)/SCALE
      S=S+U(K,I)**2
  130 CONTINUE
      F=U(I,I)
      G=-SIGN(SQRT(S),F)
      H=F*G-S
      U(I,I)=F-G
      IF(I .EQ. N)GO TO 190
      DO 150 J=L,N
      S=0.0
      DO 140 K=I,M
  140 S=S+U(K,I)*U(K,J)
      F=S/H
      DO 150 K=I,M
      U(K,J)=U(K,J)+F*U(K,I)
  150 CONTINUE
  190 DO 200 K=I,M
  200 U(K,I)=SCALE*U(K,I)
  210 W(I)=SCALE*G
      G=0.0
      S=0.0
      SCALE=0.0
      IF(I .GT. M .OR. I .EQ. N)GO TO 290
      DO 220 K=L,N
  220 SCALE=SCALE+ABS(U(I,K))
      IF(SCALE .EQ. 0.0)GO TO 290
      DO 230 K=L,N
      U(I,K)=U(I,K)/SCALE
      S=S+U(I,K)**2
  230 CONTINUE
      F=U(I,L)
      G=-SIGN(SQRT(S),F)
      H=F*G-S
      U(I,L)=F-G
      DO 240 K=L,N
  240 RV1(K)=U(I,K)/H
      IF(I .EQ. M)GO TO 270
      DO 260 J=L,M
      S=0.0
      DO 250 K=L,N
  250 S=S+U(J,K)*U(I,K)
      DO 260 K=L,N
      U(J,K)=U(J,K)+S*RV1(K)
  260 CONTINUE
  270 DO 280 K=L,N
  280 U(I,K)=SCALE*U(I,K)
  290 ANORM=AMAX1(ANORM,ABS(W(I))+ABS(RV1(I)))
  300 CONTINUE
      IF(.NOT. MATV)GO TO 410
      DO 400 II=1,N
      I=N+1-II
      IF(I .EQ. N)GO TO 390
      IF(G .EQ. 0.0)GO TO 360
      DO 320 J=L,N
  320 V(J,I)=(U(I,J)/U(I,L))/G
      DO 350 J=L,N
      S=0.0
      DO 340 K=L,N
  340 S=S+U(I,K)*V(K,J)
      DO 350 K=L,N
      V(K,J)=V(K,J)+S*V(K,I)
  350 CONTINUE
  360 DO 380 J=L,N
      V(I,J)=0.0
      V(J,I)=0.0
  380 CONTINUE
  390 V(I,I)=1.0
      G=RV1(I)
      L=I
  400 CONTINUE
  410 IF(.NOT. MATU)GO TO 510
      MN=N
      IF(M .LT. N)MN=M
      DO 500 II=1,MN
      I=MN+1-II
      L=I+1
      G=W(I)
      IF(I .EQ. N)GO TO 430
      DO 420 J=L,N
  420 U(I,J)=0.0
  430 IF(G .EQ. 0.0)GO TO 475
      IF(I .EQ. MN)GO TO 460
      DO 450 J=L,N
      S=0.0
      DO 440 K=L,M
  440 S=S+U(K,I)*U(K,J)
      F=(S/U(I,I))/G
      DO 450 K=I,M
      U(K,J)=U(K,J)+F*U(K,I)
  450 CONTINUE
  460 DO 470 J=I,M
  470 U(J,I)=U(J,I)/G
      GO TO 490
  475 DO 480 J=I,M
  480 U(J,I)=0.0
  490 U(I,I)=U(I,I)+1.0
  500 CONTINUE
  510 DO 700 KK=1,N
      K1=N-KK
      K=K1+1
      ITS=0
  520 DO 530 LL=1,K
      L1=K-LL
      L=L1+1
      IF(ABS(RV1(L))+ANORM .EQ. ANORM)GO TO 565
      IF(ABS(W(L1))+ANORM .EQ. ANORM)GO TO 540
  530 CONTINUE
  540 C=0.0
      S=1.0
      DO 560 I=L,K
      F=S*RV1(I)
      RV1(I)=C*RV1(I)
      IF(ABS(F)+ANORM .EQ. ANORM)GO TO 565
      G=W(I)
      H=SQRT(F*F+G*G)
      W(I)=H
      C=G/H
      S=-F/H
      IF(.NOT. MATU)GO TO 560
      DO 550 J=1,M
      Y=U(J,L1)
      Z=U(J,I)
      U(J,L1)=Y*C+Z*S
      U(J,I)=-Y*S+Z*C
  550 CONTINUE
  560 CONTINUE
  565 Z=W(K)
      IF(L .EQ. K)GO TO 650
      IF(ITS .EQ. 30)GO TO 1000
      ITS=ITS+1
      X=W(L)
      Y=W(K1)
      G=RV1(K1)
      H=RV1(K)
      F=((Y-Z)*(Y+Z)+(G-H)*(G+H))/(2.0*H*Y)
      G=SQRT(F*F+1.0)
      F=((X-Z)*(X+Z)+H*(Y/(F+SIGN(G,F))-H))/X
      C=1.0
      S=1.0
      DO 600 I1=L,K1
      I=I1+1
      G=RV1(I)
      Y=W(I)
      H=S*G
      G=C*G
      Z=SQRT(F*F+H*H)
      RV1(I1)=Z
      C=F/Z
      S=H/Z
      F=X*C+G*S
      G=-X*S+G*C
      H=Y*S
      Y=Y*C
      IF( .NOT. MATV)GO TO 575
      DO 570 J=1,N
      X=V(J,I1)
      Z=V(J,I)
      V(J,I1)=X*C+Z*S
      V(J,I)=-X*S+Z*C
  570 CONTINUE
  575 Z=SQRT(F*F+H*H)
      W(I1)=Z
      IF(Z .EQ. 0.0)GO TO 580
      C=F/Z
      S=H/Z
  580 F=C*G+S*Y
      X=-S*G+C*Y
      IF(.NOT. MATU)GO TO 600
      DO 590 J=1,M
      Y=U(J,I1)
      Z=U(J,I)
      U(J,I1)=Y*C+Z*S
      U(J,I)=-Y*S+Z*C
  590 CONTINUE
  600 CONTINUE
      RV1(L)=0.0
      RV1(K)=F
      W(K)=X
      GO TO 520
  650 IF(Z .GE. 0.0)GO TO 700
      W(K)=-Z
      IF(.NOT. MATV)GO TO 700
      DO 690 J=1,N
  690 V(J,K)=-V(J,K)
  700 CONTINUE
      GO TO 1001
 1000 IERR=K
 1001 RETURN
      END
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NRC FORM 335
(2-84)
NRCM 1102,
3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

1 REPORT NUMBER *(Assigned by TIDC, add Vol. No., if any)*
NUREG/CR-4116

2 TITLE AND SUBTITLE
NUFREQ-NP: A Digital Computer Code for the Linear Stability Analysis of Boiling Water Nuclear Reactors

3 LEAVE BLANK

4 DATE REPORT COMPLETED

MONTH	YEAR
September	1984

5 AUTHOR(S)
S.J. Peng, M.Z. Podowski, R.T. Lahey, Jr.

6 DATE REPORT ISSUED

MONTH	YEAR
August	1985

7 PERFORMING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
Rensselaer Polytechnic Institute
Troy, NY 12181

8 PROJECT/TASK/WORK UNIT NUMBER

9 FIN OR GRANT NUMBER
B7230

10 SPONSORING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
Division of Accident Evaluation
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

11a TYPE OF REPORT
Technical

b PERIOD COVERED *(Inclusive dates)*

12 SUPPLEMENTARY NOTES

13 ABSTRACT *(200 words or less)*

The phenonema of nuclear-coupled density-wave oscillations are of considerable importance in boiling water nuclear reactor (BWR) stability analysis. A state-of-the-art linear frequency domain digital computer code, NUFREQ-NP, has been developed for either forced or natural circulation BWR stability analysis. The NUFREQ-NP code can be excited by many external perturbations, including system pressure perturbation. It is based on one dimensional drift-flux thermal hydraulics, and allows for subcooled boiling, arbitrary nonuniform axial and radial power shapes, distributed local losses (e.g., spacers), point or multi-dimensional neutron kinetics, and detailed fuel element dynamics. It has been compared with both out-of-core and in-core data, and good agreement has been found.

14 DOCUMENT ANALYSIS - a KEYWORDS/DESCRIPTORS
density-wave
BWR
stability analysis

b IDENTIFIERS/OPEN ENDED TERMS

15 AVAILABILITY STATEMENT
Unlimited

16 SECURITY CLASSIFICATION
(This page)
Unclassified
(This report)
Unclassified

17 NUMBER OF PAGES

18 PRICE

430

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